A CONCISE HISTORY OF SCIENCE IN INDIA

'La catégorie qui s'est intéressée aux sciences comprend huit peuples: les Indous, les Perses, les Chaldéens, les Hébreux, les Hellènes, les *Rûm*, les Egyptiens et les Arabes. ... La première nation (qui ait cultivé les sciences) est celle des Indous. Elle est fort importante, très nombreuse, formée de royaumes puissants. On la connait pour sa sagesse et tous les peuples disparus, toutes les générations passées témoignent qu'elle s'est distinguée dans les diverses branches du savoir. ... Les Indous, entre toutes les nations, à travers les siècles et depuis l'Antiquité, furent la source de la sagesse, de la justice et de la modération. Ils furent un peuple donné de vertus pondératrices, créature de pensées sublimes, d'apologues universels, d'inventions rares et de traits d'esprit remarquables.'

Ṣā'id al-Andalusī (Arab astronomer and historian of science of the eleventh century A.D.), *Kitāb Ṭabaḳāt al-Umam* (Livre des catégories des nations), translated into French from Arabic by Régis Blachère, Paris, 1935, pp. 35, 43, 44.

A CONCISE HISTORY OF SCIENCE IN INDIA

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PREFACE

There is a world-wide interest in the study of the history of science today as one important aspect in understanding man's cultural patterns. This book attempts to present a concise account of the development of science in one of the most ancient culture areas of the world. Despite vicissitudes in intellectual and scientific endeavours and periods of stagnation, e.g. about the time of the Renaissance in Europe, the Indian subcontinent is one of the few areas where a fairly continuous tradition in science and technology is clearly seen.

Growing interest in Indological research from the end of the eighteenth century saw new approaches to oriental studies. Anquetil du Perron and Sir William Jones, among several others, were pioneers in this field. The search for and the discovery of manuscripts, their patient study, attempts at correlation with the relics of antiquity brought to light by the archaeologist's spade and efforts to understand developments in one culture area in the light of those of other culture areas in contemporary periods characterized this orientation. The linguists, the philologists and the general historians trained in the liberal arts, who led the way, were naturally attracted to the vast sacerdotal and canonical texts, law books, epics, drama and literature. These were more than sufficient to absorb their energies. The study of ancient and medieval Indian technology and science which involved the methods of the linguist and the philologist and the knowledge of scientific disciplines had at first to be slow and halting. Nevertheless, such studies were developing and making important contributions to the understanding of the progress of science in ancient and medieval India. The history of Indian science, however, was a far cry until after World War II.

The genesis of the current interest in the history of science may be traced to the Symposium on the History of Sciences in South-East Asia held in Delhi in 1950 under the joint auspices of the UNESCO and the Indian National Science Academy (then the National Institute of Sciences of India). The Symposium emphasized the need for an integrated study of the history of science in India and for straightening out the chronological problems. It favoured the co-operation of scientists and historians in an area of endeavour where the methods of their divergent disciplines could be most fruitfully applied.

After a period of initial deliberations and discussions among its Fellows, the Academy set up a History of Science Board and, with the

funds provided by the Government of India in the then Ministry of Scientific Research and Cultural Affairs, started research units for the collection and study of source materials for the eventual compilation, in several volumes, of the History of Sciences in India. During 1964–65, the Board was replaced by a National Commission composed of a number of scientists and historians in keeping with the recommendations of the 1950 Symposium.

While the Academy, through its History of Science Board and the National Commission, was thus busy in developing the foundation of study and research in the history of science, the universities and educational institutions evinced a growing interest in the teaching of the subject, and a number of institutions included it in their curricula. From its inception, the National Commission was keenly aware that the universities should take an active interest in introducing teaching and research in the history of science and made a number of recommendations in that direction. In such circumstances, the publication of a concise history of science in India was considered to be an effective way of stimulating further appreciation among the universities in encouraging teaching in the subject apart from generating interest in this new discipline among scholars, scientists and general readers.

The editors are conscious of the limitations of their attempt involving the participation of a number of scholars from different fields. Certain lack of uniformity in the treatment and presentation of the materials is perhaps unavoidable. Nevertheless, it has given an opportunity to such scholars to look at the history of science in India from the viewpoint of their own disciplines. The original draft of each chapter was referred to other experts for comments and suggestions for further improvement, which were freely given. Many of these suggestions bearing on the factual statements were incorporated and comments concerning points of view were considered in such a manner that the freedom of authors in this respect was not interfered with. The editors take this opportunity to express their gratitude to the referees—Prof. Ram Ballabh, Shri T. S. Kuppanna Sastry, Prof. Ram Behari, Dr. C. Dwarkanath, Hakim Abdul Wahab Zahuri, Prof. T. R. Seshadri, Prof. P. Rây, Shri B. B. Lal, the late Dr. J. C. Sengupta and Dr. G. S. Melkote.

The drafts of the various chapters developed in the aforesaid manner were considered by the Commission at one of its meetings early in 1970. The Commission suggested, *inter alia*, the incorporation of an introductory chapter containing a survey of source materials, rationalization and avoidance of duplication of the treatment of sources, citations of references in the form of footnotes and preparation of a consolidated bibliography, covering both primary and secondary sources, and a résumé highlighting the main achievements in a chronological setting. The editors executed these tasks in consultation with four historian members of the National Commission, Prof. R. S. Sharma, Prof. G. R. Sharma, Prof. S. Nurul Hasan

and Prof. Satish Chandra, and received from them valuable suggestions in the course of this work, for which they record their thanks. The editors' thanks are also due to Prof. Sukumar Roy, formerly Head of the Department of Islamic Studies and Culture, University of Calcutta, for going through the draft manuscript, particularly sections dealing with the medieval period, and making a number of useful suggestions. Prof. F. C. Auluck, Member-Secretary of the National Commission, read the draft of individual chapters. The editors would like to thank him for his many suggestions and for facilitating the progress of the work in various ways.

Both in the course of the writing of the chapters and their editing, the editors received ungrudging co-operation from a number of institutions and persons in the matter of references, books and journals, drawings and sketches and many technical points. While it is not possible to list all of them by name, particular mention may be made of the Asiatic Society Library, the National Library, the Library of the Indian National Archives, the Archaeological Survey of India, the Zoological Survey of India, the Botanical Survey of India, the India Meteorological Department, the Geological Survey of India, Dr. B. Biswas, Dr. Y. P. Rao, Shri M. V. A. Sastry, Shri M. N. Deshpande, Shri S. R. Rao, Shri M. C. Joshi, Dr. S. P. Gupta, Prof. G. S. Dikshit and Dr. R. N. Kapil. To all of them, including those not specifically mentioned, the editors place on record their sincere thanks for their valuable co-operation and help.

Special thanks are due to Dr. A. K. Bag, Miss Mira Roy, Miss Mamata Chowdhuri and Shri Vijay Govind, Research Fellows in History of Science under the National Commission, for rendering all kinds of assistance, particularly in the preparation of the consolidated bibliography, the checking of references and going through the proofs, and to Mrs. Sandhya Mitra, Assistant Editor of the *Indian Journal of History of Science* and other publications of the Academy, for seeing the entire matter through the press. The editors deeply appreciate the typing and administrative assistance given by Shri S. K. Sandhar, Shri B. N. Chakraburtty and Shri S. K. Roy.

Finally, the editors record their sincere thanks to the Baptist Mission Press, particularly to its energetic Works Manager Shri G. Banerjee and his assistants, for their meticulous care and interest in the printing of the book.

EDITORS

Calcutta
October 15, 1971

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1 A SURVEY OF SOURCE MATERIALS

S. N. SEN

THE source materials on the basis of which attempts have been made in this book to present a connected account of the development of science in India largely comprise archaeological findings, the vast range of the Sanskrit literature originating from the Vedic times, the canonical as well as the secular literature of the Buddhists and the Jainas, Arabic and Persian works, and secondary sources representing scholarly studies, interpretations and analyses of these materials. The scientific and technical writings, both primary and secondary, have formed the main basis of discussions of the various sciences, and as such these have been treated, along with their scientific and technical contents, in the respective chapters. Here, for the sake of completeness, we shall do no more than mention some important texts.

The position is quite different with regard to sacerdotal texts, canonical literature, philosophical compendia, encyclopaedic works like the *Bṛhat-saṃhitā*, *Arthaśāstra* (work on polity), epics, *purāṇas*, lexicographies and so on in which scientific matters and concepts appear incidentally, mixed up with the non-scientific, but which are nevertheless exceedingly important from the point of view of the history of the development of scientific ideas. The scientific contents and their analyses will, however, appear in their proper places in the chapters concerned, but in this survey we shall give an account of such general sources, including the archaeological, and their chronological position, so that we may not have to refer to them again and again.

ARCHAEOLOGICAL SOURCES

The archaeologist's spade has turned up objects of great value pertaining to prehistoric, protohistoric and historical periods. Here our main concern will be with pre- and protohistory and consequently with objects typical of these periods, which throw light on the various arts and techniques from which later scientific practices and methods developed.

The terms 'prehistory' and 'protohistory' and the various cultural divisions within them require some clarification. The beginning of the historical period is now generally determined by the advent of written documents of historical character such as the Aśokan edicts; in other words, the history of a people begins from when they have become literate and mastered the art of writing. Accordingly, accounts of all cultures in which writing has not yet appeared should come under 'prehistory'. Such a definition as far as concerns the Indian subcontinent is fraught with serious difficulties. The Harappan civilization, for example, is marked by a kind of writing, albeit undeciphered, and the builders of that civilization can by no means be called illiterate. Furthermore, how should we describe the account of a people who orally transmitted the literary tradition of the *Vedas* for several centuries since the second millennium B.C.—a tradition rich in near historical materials but committed to writing at a much later date? To resolve these difficulties, the term 'protohistory' is now used to cover the civilization of the Indus valley, the Vedic civilization and the various chalcolithic cultures either contemporaneous with, or successors to, the Indus civilization.[a] The term 'prehistory' is then reserved for the Stone Age cultures for the understanding of which we have no guideline other than stone (and bone) implements.

About the various prehistoric cultures, terms like 'palaeolithic', 'mesolithic', 'neolithic'. 'Bronze Age', etc., used in the context of the European and the Mediterranean world, are not quite applicable to the Indian subcontinent owing to differences in cultures and techniques. We have abundant evidence of Stone Age cultures from the time of the interglacial periods of the Pleistocene, and it is now thought more appropriate to describe them as Early, Middle and Late Stone Age on the basis of the major types of stone industries. There is not much difficulty in using the term 'neolithic' to designate the cultures characterized by some kind of mixed farming, domestication of animals, use of potteries, building of dwellings and so on in which stone is still the material of the tools and implements used. In India, the stone-using farm cultures and the metal-using (copper and bronze) ones are not sharply delineated, the term 'chalcolithic' being applied to metal-using farm cultures. On account of the coexistence of both the cultures, the period is often described as the 'neolithic-chalcolithic'. The term 'Bronze Age' cannot be used in India in the same sense in which it is meaningful for the Mediterranean world and elsewhere although bronze found use in the subcontinent at quite an early date and became the distinctive feature of the Harappan culture. The Harappan culture, the so-called Indus Valley Civilization, extended as recent researches have revealed, much beyond the limits of the Indus valley, and in this context pre-Harappan and post-Harappan cultures are now used to follow the sequence.

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[a] Sankalia (4), pp. ix–x.

Within the broad neolithic-chalcolithic framework, cultural differentiation as well as affinities are often sought to be made by pottery types such as handmade, wheel-thrown and wheel-turned, with painted decorations varying from monochrome to polychrome, typical of pre-Harappan Baluchistan, Black and Red wares of Harappan and post-Harappan Lothal, Ahar, Rangpur, Prakash and many other sites, technologically innovated Lustrous Red wares believed to be evolved from Harappan types and found in chalcolithic Saurashtra, and finally the Painted Grey and Northern Black Polished wares associated with an Iron Age in India and turned up at Atranjikhera, Hastinapur, Alamgirpur and other sites in the Doab.

The Stone Age

Of the three phases of the Indian Stone Age, the Early is dominated by the hand-axe, the cleaver and core tools, the Middle by the flakes including scrapers, burins and blades, and the Late by microliths of various types. Quartzite pebbles, stone outcrops and boulders, cryptocrystalline silica like agate, jasper or chalcedony provided the main materials for the stone industries. Some of the Early Stone Age sites include the Soan (or Sohan) and the Beas valley in the Panjab, Adamgarh Hill and Bhera Ghat near Jabalpur in the Narbada valley, the Gudiyam Cave at Attirampakkam near Madras, Wainganga River sites, Nevasa on the Godavari, Khandivli near Bombay and a few other places. Most of the sites mentioned above have also revealed Middle Stone Age flake industries. The Late Stone Age sites are widespread throughout the Indian subcontinent. Gujarat (Langhnaj), Central India (Adamgarh, Barasimha, Nimkhera, Sakri, etc.), the region between the Central Indian hills and the Gangetic plains (Barakaccha, Sidhpur, Lekhania in Mirzapur district, and Morhana Pahar), Birbhanpur on the Damodar in West Bengal, and south India (Raichur, Jalahalli, Kibbanahalli, Nagarjunakonda and Belgaum) are particularly rich in Late Stone Age sites. Adamgarh alone has yielded 25,000 microliths. The Old Stone Age sites in Kashmir and Panjab are related to interglacial periods of late Pleistocene (150000 B.C.), the Middle Stone Age cultures which are often mixed with the later phase of the former flourished around *c.* 25000 B.C., while the Late Stone Age emerged definitely during the post-Pleistocene and merged with the Neolithic.[a] C^{14} dating of shells from Adamgarh carried out at the Tata Institute of Fundamental Research has placed the beginning of the Late Stone Age in that area at 5500 B.C. At Lekhania, the Late Stone Age flourished as late as 1710 B.C. Our main sources of Indian Stone Age cultures are the pioneering investigations of R. B. Foote and F. R. Allchin in South India and Gujarat, H. de Terra and T. T. Paterson in Kashmir, the Panjab and Central India, L. A. Cammiade and M. C. Burkitt in South India, K. R. U. Todd for the Bombay region, R. V. Joshi for Adamgarh and other Madhya Pradesh sites,

[a] Sankalia (4), pp. xxi–xxii.

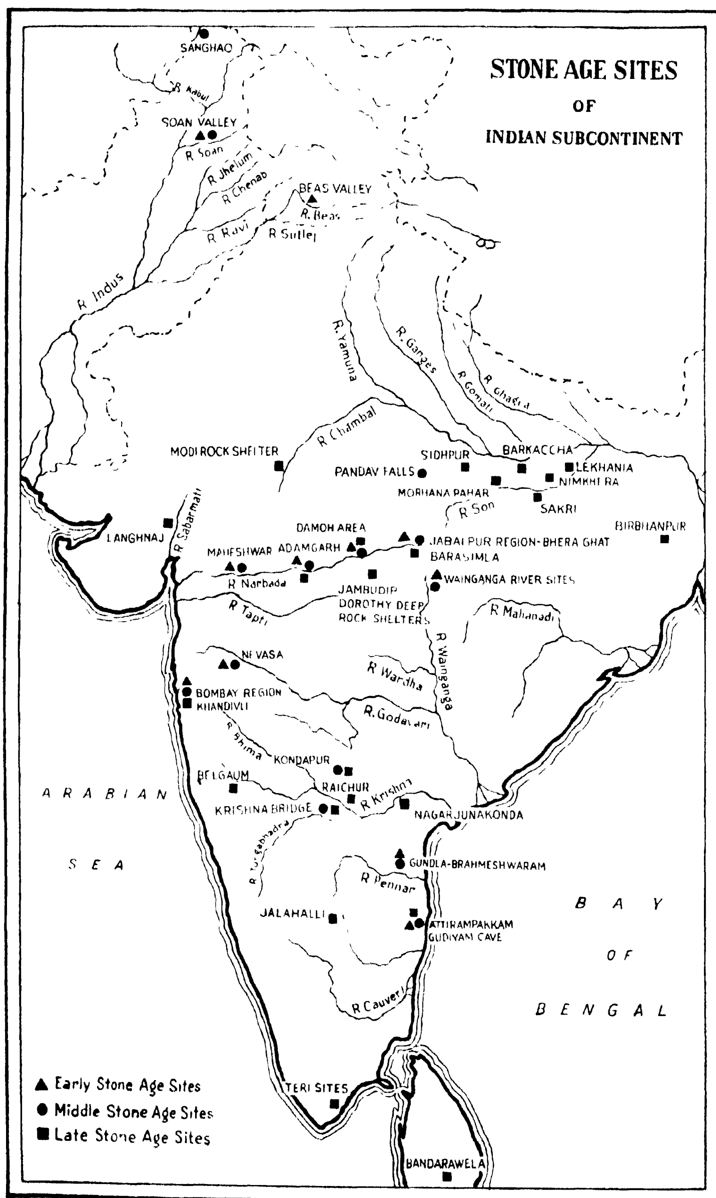


FIG. 1.1. Map showing Early, Middle and Late Stone Age sites.

H. D. Sankalia for Bombay and Maharashtra regions, B. B. Lal for Birbhanpur, Beas and Banganga valleys, V. D. Krishnaswami and K. V. Soundara Rajan for Southern India. The results of these investigations will be found in the pages of the *Ancient India*, the *Man*, the Deccan College Monograph series, and a number of general studies by de Terra and Paterson, Sankalia and others.

Pre-Harappan Cultures

Pre-Harappan cultures in various stages of evolution have recently assumed clearer perspective as a result of intensive archaeological activity in Baluchistan, Sind, the Panjab and Rajasthan. In north Baluchistan, earliest settlements have been found in Kili Ghul Mohammad and Damb Sadaat in the Quetta valley by Fairservis and at Rana Ghundai mound in the Loralai valley by Ross, all showing a number of periods. Pd. I of Kili Ghul Mohammad dated 3688 and 3712 by C^{14} methods produced no pottery nor metal objects, Pd. II yielded handmade pottery and Pd. III both handmade and wheel-turned pottery as well as copper.[a] Damb Sadaat, excavated by Fairservis, shows three periods, with somewhat continuous development, dating from 2528 or 2625 B.C. for Pd. I and 2554, 2425 or 2220 B.C. for Pd. II. Wheel-turned pottery, terracotta figurines and copper objects (Pd. II and III) are among some of the finds. Rana Ghundai excavated by Ross yielded a complete sequence through a number of periods.

At Anjira and Siah-damb in the Surab valley in central Baluchistan, de Cardi unearthed similar neolithic settlements having pottery affinities with Damb Sadaat. Further south, Nal, in Kalat State, settled somewhat later than northern and central sites, produced distinctive types of pottery, copper objects and evidence of lead smelting.

These earliest settlements in semi-arid and mountainous Baluchistan in the subcontinent show unmistakable cultural affinities, as, for example, Damb Sadaat I with Kili Ghul Mohammad IV, Anjira III with Damb Sadaat II–III, Anjira II with Kili Ghul Mohammad II and III, Nal with Rana Ghundai III and so on. The most important, however, is the relationship of these settlements with the earlier neolithic settlement at Mundigak in south Afghanistan, which reveals a progressive evolution in culture, through periods I to IV, in pottery types from wheel-made to wheel-turned with varying designs and motifs, in the appearance of copper in Pd. I_2, bronze in Pd. III_6, stone seals and in the development of some kind of township with walls and bastions with sun-dried bricks. In some of these features, Mundigak IV corresponds to Damb Sadaat III and Rana Ghundai III_c, Mundigak II–III to Damb Sadaat I–III, Mundigak IV to Nal, whereas in its later phase, Mundigak itself bears the impress of the Harappan

[a] By Pd. I, Pd. II, etc., are meant period I, period II, etc., the Roman numbers in ascending order indicating later dates. In several cases, dates of these archaeological periods have been given.

culture. Some of the radiocarbon datings for Mundigak are : Pd. I_5—2113 B.C.; Pd. III—2360 B.C.

As we move from Baluchistan to the Indus valley, we come across a number of sites, e.g. Amri excavated by Majumdar and later by Casal, Kot Diji explored by the Pakistan Archaeological Department, and Kalibangan[a] on the Ghaggar excavated by Lal and Thapar, and the pre-defence layers of Harappa itself. All these sites present the pre-Harappan phase in a more marked manner. A fine dark, purple-red ware is the characteristic feature of all these sites. At Amri, different phases of period I show affinities with Anjira III, Kili Ghul Mohammad III–IV and Mundigak III, while during period II Harappan types appear. Kot Diji, about 30 miles east of Mohenjo-daro, at its levels of earliest settlements, reveals pottery types akin to Mundigak III and IV and Anjira III–IV and, at later levels, a mixed culture in which the Harappan is predominant. Radiocarbon datings carried out at the University of Pennsylvania are 2605 B.C. and 2472 B.C. for the early period and 2335 B.C., 2255 B.C. for the later period. At Kalibangan, the Harappan citadel phase is preceded by the pre-Harappan settlement characterized by steatite beads, shell bangles, some pottery types resembling those of Amri and Kot Diji, and a few copper and bronze objects as rarities. C^{14} datings determined by the TF on a large number of samples from Kalibangan place its pre-Harappan phase between 2371 B.C. and 2098 B.C. although a few lower dates have also been found.

Harappan Culture : The Bronze Age Civilization of the Indus Valley

The brilliant series of excavations started by Daya Ram Sahni at Harappa in 1921 and by R. D. Banerjee at Mohenjo-daro during 1922–23 and followed up by Vats, Dikshit, Marshall, Hargreaves, Mackay and Majumdar led to the exciting discovery of the protohistoric Harappan culture which up to 1947 or so was believed to have been confined within the narrow strip of the Indus valley. Archaeological explorations carried out during the post-Independence period have now resulted in the extension of this civilization over an area of about 840,000 square miles.[b] Besides the Indus valley proper, this area now includes East Panjab and Uttar Pradesh almost up to Delhi, northern Rajputana in the former State of Bikaner, Cutch, Saurashtra and Gujarat up to the mouth of the Narbada and the Makran coastal area in South Baluchistan up to Sutkagen Dor near the Iranian frontier. Over 70 sites, large and small, have so far yielded remains of this once extensive culture, of which some of the important ones of recent discovery include Rupar[c] on the Sutlej in the Himalayan foothills, Alamgirpur[d] in Meerut district, Kalibangan[e] in northern Rajasthan, Desalpar[f] in Cutch, Lothal[g] and Rojdi[h] in Saurashtra, Kot Diji and Amri in Sind.

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[a] *IAR*, 1960–61, pp. 30–31; 1961–62, pp. 39–44; 1962–63, pp. 20–31.
[b] Sankalia (4), p. 155.
[c] *IAR*, 1953–54.
[d] *IAR*, 1958–59.
[e] In addition to reference already given, 1963–64; 1964–65.
[f] *IAR*, 1963–64.
[g] *IAR*, 1954–55; 1955–56; 1956–57; 1957–58; 1958–59.
[h] *IAR*, 1957–58; 1958–59; 1962–63.

The general characteristics of this civilization as enumerated by Wheeler (3) include a thick red-slipped ware in cylindrical and goblet shapes, intersecting circles, *pipal* leaves, rosettes, and peacocks as motifs, Indus seals and script, triangular terracotta cakes, kidney-shaped inlays of shell

FIG. 1.2. Map showing principal pre-Harappan settlements, and Harappan and post-Harappan sites.

or faience, metal tool types, and town planning according to a gridiron scheme of streets and houses. A cultural uniformity, unquestionable technical competence, if dull, and a flare for standardization are noticeable in all areas of activity—in the making of bricks, in sanitary arrangements, in pottery, in the wide range of copper and bronze tools, vessels and human and animal figurines, and seal-cutting from steatite blocks. In this effortless competence of which evidence has survived in archaeological remains of all descriptions, one can see the picture of city-centered prosperous agricultural communities thriving on wheat, barley, sesamum and mustard, animal husbandry, an industry of woven cotton, various arts and crafts and an extensive trade, all rendered possible by an efficient central government

with capitals, defensive city outposts, docks and harbours. The Harappan inscriptions, now numbering about 2,500, have so far defied several attempts at decipherment. B. B. Lal (5) has shown the direction of writing from right to left. It is still an open question if the language belonged to the Indo-European or the Dravidian family, but recent computer studies carried out in Copenhagen by a team of Finnish scholars indicate a preference for the latter.[a]

Marshall's estimate of 3250–2750 B.C. as the period of the Harappan culture was already scaled down to 2350–1770 B.C. by C. J. Gadd on the basis of cross-datings with the Sargonic and Isin-Larsa periods. Wheeler's (3) dating of 2500–1500 B.C. for the entire Harappan span, first suggested in 1946, remained generally accepted up to 1962. Radiocarbon datings largely carried out at the TF and recently analyzed by Agrawal have introduced further refinements in the above date-brackets. Some of these datings are given below :[b]

Mohenjo-daro, Sind		B.C.
TF-75	Harappan level	1760 ± 115
P-1182A	Mature Harappan	1864 ± 64
P-1176	,,	1966 ± 60
P-1180	,,	1993 ± 61
P-1177	,,	2062 ± 66
P-1179	,,	2083 ± 66
Kot Diji, Sind		
P-195	pre-Harappan, Late	2090 ± 138
P-180	,,	2255 ± 140
P-179	,,	2335 ± 156
P-196	,,	2605 ± 145
Kalibangan, Rajasthan		
TF-161	pre-Harappan	2098 ± 103
TF-162	,,	2108 ± 103
TF-241	,,	2263 ± 93
TF-157	,,	2283 ± 103
TF-155	,,	2371 ± 118

Kalibangan, Rajasthan		B.C.
TF-138	Harappan	1217 ± 103
TF-143	,,	1665 ± 113
TF-149	,,	1835 ± 145
TF-150	,,	1900 ± 105
TF-147	,,	2030 ± 105
TF-163	,,	2077 ± 103
TF-160	,,	2236 ± 103
Rojdi, Rajasthan		
TF-199	Harappan IB	1745 ± 105
TF-200	,,	1970 ± 115
Lothal, Gujarat		
TF-135	Harappan, Pd. IIA	1555 ± 130
TF-23	,, Pd. IIVA	1866 ± 108
TF-27	,, Pd. I, IIIB	2005 ± 113
TF-136	,, Pd. IA	2080 ± 135

From a careful analysis of these and other radiocarbon data, D. P. Agrawal (2) concluded that for the metropolitan Mohenjo-daro the maximum spread might be taken as 2300 to 2000 B.C. and for the peripheral regions 2200 to 1700 B.C. would be best indicated by these findings.

[a] *See* a note on 'Harappan may be Dravidian', *Scientific American*, November 1969, p. 62. For fuller information, Clauson, Gerard, and Chadwick, John, pp. 200–207.

[b] Carbon-dating figures are taken from Allchin (B. and R.). To obtain B.C. dates 1950 has been subtracted. P = University of Pennsylvania, U.S.A.; TF = Tata Institute of Fundamental Research, Bombay; figures following abbreviations indicate sample numbers.

Neolithic-Chalcolithic Cultures outside the Harappan limits

What was happening in the rest of India when cultural evolution was taking place in the western regions of the subcontinent culminating in the brilliant Harappan phase between the fourth millennium to the middle of the second millennium B.C.? Until Wheeler's work at Brahmagiri during 1947–48, northern, central, southern and eastern India formed the archaeological *terra incognita*, contrary to expectations raised by many references in the Sanskrit and the Buddhist literature. During the last 20 years, archaeological excavations in these regions have established the existence of neolithic and chalcolithic cultures in all these areas as is naturally to be expected from the extensive Stone Age cultures prevailing in prehistoric times in these very regions. In Kashmir, Burzahom[a] gave evidence of a neolithic site, dated *c.* 2375 by the C^{14} method, whose stone and bone implements, coarse handmade pottery, pit dwellings, and dog burial custom indicated Burzahom's inspiration from China. This is also true of the neolithic settlements of Assam in the Garo and Naga Hills.

In south India where Brahmagiri gave the first indication, neolithic settlements have been discovered at Sanganakallu,[b] Piklihal,[c] Maski,[d] Utnur, Tekkalakota,[e] Hallur,[f] T. Narsipur,[g] Hemmige, Nagarjunakonda and other places, all in Andhra-Karnatak and at Paiyampalli, Gaurimedu and Mangalam in the Tamilnad. Radiocarbon datings indicate the comparative lateness of the South Indian neolithic complex, say, between 2000 B.C. and 1485 B.C. One of the samples from Utnur gave as early a date as *c.* 2295 B.C. Narsipur and Tekkalakota gave 1805 and 1780 B.C. Paiyampalli, Sanganakallu, and later phases of Narsipur and Tekkalakota appeared between 1485 and 1615 B.C. Sequential changes from core and flake tradition and simple handmade pottery to more developed wheel-thrown pottery and adoption of copper and bronze tools in the late phase are clearly noticeable. Sankalia thought that Raichur and Bellary were probably the original focus of neolithic cultures in South-east India and stimulated the development of similar cultures in Andhra-Karnatak and Tamilnad regions.[h] Allchin favours Daimabad in Maharashtra as a focal point which in its turn received inspiration from the Harappan cultures and even from Burzahom as far as early pottery is concerned.[i]

More interesting perhaps are the post-Harappan phases, mixed with local cultures, discovered in Saurashtra, Maharashtra, south-east Rajasthan and Malwa, the Panjab and the Gangetic Doab. In Saurashtra, the Harappan phase noticed in Lothal, Rojdi and Desalpar yielded to a post-Harappan phase in Lothal II (1900–1500 B.C.) and Rojdi IB (1800 B.C.).

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[a] *IAR*, 1960–61; 1961–62; 1962–63.
[b] Subbarao, pp. 5 ff.
[c] Allchin (F. R.).
[d] Thapar (1).
[e] Nagaraja Rao.
[f] *IAR*, 1964–65.
[g] *IAR*, 1959–60; 1961–62.
[h] Sankalia (4), p. 247.
[i] Allchin (B. and R.), p. 168.



FIG. 1.3. Map showing principal neolithic and chalcolithic sites.

To these sites may be added Rangpur,[a] Prabhas Patan (Somnath),[b] Bhagatrav and a few other places. In all of them, after an initial decline of the Harappan culture, a new revival is noticeable as in the Black and Red pottery styles and the appearance of the Lustrous Red wares. At Rangpur, rice cultivation appears in Pd. IIA (2000–1750 B.C.) and millet in Pd. III (1200–1000 B.C.). In the concluding phase of Prabhas Patan, iron appears around 1000 B.C. At Lothal and Rojdi, this period possibly commenced after 1800 B.C. and 1745 B.C. respectively; at other places the period might be somewhat later.

The Banasian culture of Ahar[c] and Gilund[d] in the Banas river valley in south-east Rajasthan is distinctive in its absence of a stone industry of any kind in its earlier phases and in the presence of numerous copper objects, particularly axes made of locally available copper. Black and Red wares are predominant, with Lustrous Red wares appearing in later phases. Radiocarbon datings carried out in the University of Victoria, Australia, would indicate the beginning of the Ahar culture around *c.* 1990 to 2144 B.C., whereas some late dates, 1727, 1552, 1273 B.C., are indicated by samples analyzed at the TF. According to Allchin, the Banasian phase might have extended from 1800 to 1400 B.C.[e]

Further south-east lies the Malwa plateau between the Chambal and the Narbada. Here Navdatoli,[f] Nagda and a few other sites have revealed four to three phases and a cultural evolution from a stone blade industry, through cultivation of wheat, rice (first evidence from Navdatoli), lentil and oil-seeds and animal husbandry involving cattle, sheep, goat and pig, to a copper using phase. Black and Red pottery is predominant, later on absorbing the Jorwe tradition of spouted pots. Navdatoli's chalcolithic period, IIIA to IIID, has now been put down to 1657–1443 B.C. on the basis of Pennsylvania University's C^{14} datings.[g]

In the north-western part of the Deccan plateau, traversed by the Narbada and the Tapti flowing westward and the upper reaches of the Godavari and the Krishna flowing eastward, a series of chalcolithic sites have been unearthed and studied by the Archaeological Department of the Deccan College, Poona. These sites are Prakash,[h] Bahal[i] and Tekwada in the Tapti valley, Daimabad[j] and Nevasa[k] in the upper reaches of the Godavari, Sonegao[l] near the Krishna, Nasik,[m] Jorwe[m] and Chandoli[n] on the plateau itself. An integrated study of this group of Maharashtrian sites has brought to light a number of phases. Diamabad I presents the earliest phase having cultural affinities with Saurashtra and Malwa as

[a] Rao (2), pp. 5-207.
[b] *IAR*, 1955–56; 1956–57.
[c] *IAR*, 1954–55; 1955–56.
[d] *IAR*, 1959–60.
[e] Allchin (B. and R.), p. 183.
[f] *IAR*, 1957–58; *see also* Sankalia, Subbarao and Deo.
[g] One high dating 2299±72 B.C. for sample P-1476 is questionable.
[h] *IAR*, 1954–55; *see also* Thapar (2).
[i] *IAR*, 1956–57.
[j] *IAR*, 1958–59.
[k] Covered in detail by Sankalia (3).
[l] *IAR*, 1964–65.
[m] Sankalia and Deo.
[n] Deo and Ansari.

also with the upper neolithic phase of Karnatak. Stone axes, perforated ring-stone, a stone blade industry and a coarse grey pottery form the cultural complex of the first phase. In the second phase represented by Daimabad II and Prakash IA, copper knife blades, a fine reddish-brown ware and Malwa type spouted wares appear. Jorwe, Nevasa, Chandoli and Sonegao which represent the third phase yield a variety of both stone and copper implements, painted red Jorwe wares with spouts, some Lustrous Red wares, and fibres of cotton, flax and silk. C^{14} datings on samples from Sonegao put the Jorwe phase between 1375 and 1290 B.C.; the second phase (Daimabad II, Prakash IA) may be placed between *c.* 1700 and 1400 B.C. by comparison with Navdatoli IIIB and IIIC, and the first Daimabad phase before 1800 B.C.

The penetration of the Harappan culture in its latest phase into the Ganges-Jamuna Doab is attested by Alamgirpur. While a post-Harappan phase was persisting in Saurashtra, south-east Rajasthan and a few other places, this culture disappeared from the Doab. In its place we find the emergence of a new chalcolithic phase dominated by the use of a variety of copper implements. Several copper hoards—B. B. Lal[a] counted some 37—have been discovered in the Doab and in the Chota Nagpur Hills in Eastern India, of which some important sites include Bahadarabad in Saharanpur district, Rajpur Parsu, Bisauli, Fatehgarh, Santal Parganas, Baragunda, Saguna and others. An interesting point is the association of ochre coloured pottery with the copper hoard culture in these areas, which is now receiving closer investigation. The association, in some centres, of copper hoards with ochre coloured pottery as in Bisauli and Rajpur and, in some other places, their existence below the Painted Grey ware, as in Hastinapur, suggest that copper hoards might belong to ochre coloured or some such pottery of a pre-Grey Ware period.[b] As we have already noticed, chalcolithic copper implements in varying degrees of abundance have been reported from Saurashtra, Rajputana, Central India and the Deccan trap. These are largely in the form of flat axe, shouldered celt, antennae sword, dagger, ring, etc.

The Iron Age in India and its Association with Black and Red, the Painted Grey and the Northern Black Polished Wares

Compared to the introduction around 1800 B.C. of an Iron Age either in the Caucasus or in Asia Minor by the Hittites who discovered the process of smelting iron ores and kept it as a closely guarded secret for several centuries, the Iron Age in India is of recent date. About 20 years back Col. Gordon could place the beginning of this age not earlier than 250 B.C. By 1959 Wheeler, on the basis of new evidence, was able to push it back to the sixth century B.C. when the Achaemenian Empire extended up to the Panjab. The discovery in 1940–44 of a new type of pottery, the Painted

[a] Lal (1), pp. 20–39.

[b] Sankalia (4), p. 223.

Grey wares, in Ahicchatra[a] and later on in Hastinapur,[b] Rupar,[c] Panipat, Indraprastha (Puran Quila), Mathura,[d] Bairat, Sonpat, Atranjikhera,[e] Alamgirpur,[f] Noh[g] and Sravasti, all in the Doab except Noh in Rajasthan, and its association with Iron Age occupations, has thrown new light on this age and further pushed back its beginnings to around 1100 B.C. This grey pottery is made of well-levigated clay, free from impurities, and is medium to thin-walled and properly baked. In some of these P.G. ware levels, iron finds include, among others, arrow-heads, spearheads and axes in different shapes. Further east in the central Gangetic valley, in Kausambi,[h] Rajghat[i] (old Varanasi), Prahladpur,[j] Buxar[k] and Chirand[l], Black and Red wares characterize the pottery. No iron object has so far turned up in the early period, but in later periods, possibly around 500 B.C., iron appears to be introduced. Another interesting feature is thc appearance towards the end of the P.G. or B. and R. ware phase of a black lustrous pottery called the Northern Black Polished ware, dated from 500 B.C. At Atranjikhera, the P.G. ware period determined by C^{14} dating at the Tata Institute of Fundamental Research extends from 1025 to 537 B.C.; Hastinapur Pd. II gives two C^{14} dates, 573 and 506 B.C.; Noh (Rajasthan) provides 821 and 604 B.C. on the basis of radiocarbon dating carried out at the California University, Los Angeles; Kausambi yields (TF dating) 500 and 400 B.C.; Chirand (B. and R. period) 846 and 769 B.C.; and Sonepur (pre-N.B.P. period) 637 B.C. All these indicate a period between 1025 and 500 B.C., in which P.G., B. and R. and N.B.P. wares and the associated Iron Age played a dominant part.

In Gujarat, Malwa and Central India, the Iron Age follows the chalcolithic period in a general way. In these areas, iron objects appear in association with Black and Red wares, as in Prabhas Patan,[m] Nagal,[n] Nagara[o] (old Cambay), Nagda and Ujjain. Black and Red occupation levels are followed by N.B.P. wares imported probably from the Gangetic valley. This Black and Red ware in India was extensive both in space and time, and its full cultural significance is not yet understood. What appears to be certain is the dominance of both iron and the Black and Red ware about the fifth century B.C.[p]

In peninsular India, Black and Red pottery side by side with iron objects and the later N.B.P. phase have been discovered in Prakash II[q] and Bahal II towards the close of the chalcolithic period. Another important characteristic of peninsular India as well as of Ceylon is the pit

[a] Ghosh and Panigrahi, pp. 55–59.
[b] Lal (2), pp. 138–47.
[c] *IAR*, 1953–54.
[d] *IAR*, 1954–55.
[e] *IAR*, 1962–63.
[f] *IAR*, 1958–59.
[g] *IAR*, 1963–64; 1964–65.
[h] *IAR*, 1959–60; 1960–61; 1961–62; *see also* Sharma (G. R.).
[i] *IAR*, 1960–61; 1961–62; 1962–63.
[j] *IAR*, 1962–63.
[k] *IAR*, 1963–64.
[l] *IAR*, 1962–63; 1964–65.
[m] *IAR*, 1955–56.
[n] *IAR*, 1961–62.
[o] *IAR*, 1963–64; 1964–65.
[p] Sankalia (4), pp. 281–82.
[q] *IAR*, 1954–55.

burial and urn burial, also called 'megalith', in which iron objects have been found with pottery, stone objects and carnelian beads. These types of burial have been known for a long time from the excavations carried out between 1851 and 1862 by Meadows Taylor in Shorapur, by Alexander Rea between 1899 and 1904 in Adichanallur, and by Hunt between 1916 and 1924 in Raigir and Bhongir. Recently, Deshpande found three urn burials and one pit burial in Tekwada. Brahmagiri,[a] Piklihal,[b] Sanganakallu and Maski[c] carry the same type of story. Brahmagiri burial grounds, excavated by Wheeler, yielded B. and R. wares, mat-painted red pottery similar to Jorwe type and iron objects. Hallur (in south Dharwar) shows up an Iron Age fairly early, as indicated by TF radiocarbon datings of 1105 and 955 B.C. At Piklihal, Sanganakallu and Maski, iron objects, in association with copper and sometimes gold, are common in graves as well as habitational sites. The large number of south Indian megalithic or urn burial sites have yielded Black and Red ware, almost uniform types of iron objects—spade, hoe, pick-axe, sickle, wedge, crowbar, spear, knife, dagger, sword, chisel, tripod, saucer hook-lamps, occasional copper, bronze or stone objects and beads. Some grave types and burial customs, developed during the neolithic-chalcolithic period, are distinctly indigenous; some bear similarities with those of Central Asia, Iran or the Caucasus, suggesting the influence of Indo-Iranian speaking immigrants; while still others are reminiscent of practices noticed in the Levant and the south coast of Arabia.[d]

FAIENCE, VITREOUS PASTE, GLAZE AND GLASS

Faience, vitreous paste, glaze and finally glass and the techniques involved in making them appeared during the protohistoric period. Faience spindle-whorls side by side with those made of pottery have been found in Mohenjo-daro.[e] From the same Harappan phase we have the specimen of a vitreous paste,[f] an opaque glassy substance, having a chemical composition—silica—88·12%, ferric oxide—3·20%, calcium oxide—1·82%, alkali oxides—5·04% and cupric oxide—0·46% and a few vitreous slabs of carnelian blue colour of more or less the same composition. Such vitreous paste and slabs were intended to be ground to powder and then used for glazing purposes. Glazed ivory shells, faience and pottery objects have been found in Mohenjo-daro. In Egypt, green glazes appear much earlier on Badarian pottery (*c.* 4000 B.C.) and in Mesopotamia from the Jemdet Nasr period (*c.* 3000 B.C.).

True glass turns up in India rather late, at the beginning of the historical period, whereas this man-made fourth state of matter, in the form of coloured beads, are known in Egypt from predynastic graves at Naquada (4000–3500 B.C.), Abydos (3500–3250 B.C.), Qau (2600–2500 B.C.) and Dahshur

[a] Wheeler (1), pp. 187–99.
[b] Allchin (F. R.), pp. 136–39; p. 10.
[c] Thapar (1), pp. 115–19.
[d] Allchin (B. and R.), p. 229.
[e] Marshall, p. 469.
[f] *Ibid.*, p. 574.

(2100 B.C.). The art of making glass vessels has been practised in Egypt and Mesopotamia from about *c.* 1500 B.C. The earliest true glass objects in India have so far turned up in Taxila[a] in its three main mounds, Bhir (*c.* fifth century B.C.), Sirkap and Sirsukh and in Kopia in U.P. (fifth century B.C.), although references to glass in the *Śatapatha Brāhmaṇa* would indicate its use in India at a much earlier period. Other finds at Dharmarajika Stupa (*c.* first or second century A.D.), Ahicchatra (*c.* from A.D. 100 onwards), Chandravalli (*c.* first century A.D.) and Arikamedu (*c.* second century A.D.) belong to later periods. Kopia[b] has also yielded evidence of glass manufacture at the site itself. Chemical analyses of Indian specimens reveal considerable difference from those of contemporary Babylonian, Roman or Chinese glass and point to an indigenous industry. It is, however, quite possible that the technical know-how was originally derived from the craftsmen of this long-established ancient art of West Asia.

THE VEDIC LITERATURE

The Vedic literature is the oldest Indian and also the most outstanding specimen of the earliest Indo-European literary effort. Unlike the canonical literature of other great religions, which often represents a complete collection worked out in some definite time, the *Vedas* are considered to be revealed (*śruti*) knowledge *par excellence* handed down from generation to generation by a unique method of oral transmission. The whole literature has been conveniently divided, according to content and chronology in a general way, into three distinct classes, e.g. the *Saṃhitās*, the *Brāhmaṇas*, and the *Āraṇyakas-Upaniṣads*. Despite this classification, there is a great deal of unity and intermixture of materials among the three divisions. Chronologically, although the *Saṃhitās* are older than the *Brāhmaṇas* and the *Brāhmaṇas* than the *Āraṇyakas-Upaniṣads*, some of the *Brāhmaṇas* are older than, or contemporaneous with, some of the *Saṃhitās*, and likewise with the *Brāhmaṇas vis-à-vis* the *Āraṇyakas-Upaniṣads*.

The Four Saṃhitās

The *Saṃhitās* are lyrical collections of hymns, prayers, invocations, sacrificial and magical formulas, of which a great variety must have existed at one time, depending on the numerous families of the Vedic bards. We now possess only four such great collections, e.g. (i) the *Ṛgveda*, the book of strophes (*ṛcas*) or hymns and prayers (*mantras*) to be recited during sacrifices and rituals, (ii) the *Sāmaveda*, the book of melodies (*sāmans*) in accordance with which the *ṛcas* are to be sung, (iii) the *Yajurveda*, the book of sacrificial formulas (*yajūṃṣi*) available again under two distinct groups, the Black and the White, and (iv) the *Atharvaveda*, the book of magical formulas.

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[a] *ARASI*, 1919–20 (1920); *see also* Lal (B. B. Dr.), pp. 19-22.
[b] Roy and Varshney, pp. 366–68, 392.

The Ṛgveda

The *Ṛgveda* is the most ancient and important collection comprising 1,028 hymns and 10,462 *ṛcas* distributed over 10 *maṇḍalas* or books. From the researches of Bergaigne, Oldenberg, Bloomfield and others, it is now well known that these *maṇḍalas* and the hymns constituting them were formulated in different periods—how different or ancient it is impossible to say with any definiteness. The books II to VII, for example, contain the oldest hymns, and books I and X, containing an assortment of hymns on diverse subjects, including the oft-quoted cosmogonic hymns, represent the latest collections. Book IX dealing with the glorification of the *soma* drink and carrying forward the *soma*-cult of the Indo-Iranian period must be given high antiquity. The portrayal, in the oldest hymn-books, of a simple patriarchal life in small communities on the banks of the Indus, with a warm love and adoration of nature and, in the latest books, of an organized Brahminical hierarchy already propagating the virtues of a society based on caste, penetrating farther east, clearly indicates the great difference of time between the primitive origin of the hymns and their redaction into the *Ṛk-Saṃhitā* we are familiar with.

As to sciences, their origins, although couched in mythological forms, are traceable in the *Ṛgveda.* References to the threefold division of the heaven, the sun and the moon, their motions through stellar constellations, solar eclipse, division of time in days, months, year, intercalation, etc., clearly herald the beginning of astronomy and calendrical science. Interest in medicine is reflected in the fact that several of the Vedic gods occasionally play the role of physicians providing remedies. The foremost among them are the twin brothers Aśvins, sometimes also called Nāsatyas, who had the powers of healing the blind, the thin and the feeble and men with broken bones.[a] Another Vedic god who has something to do with healing is Varuṇa, the lord and guardian of *ṛta*, the Vedic equivalent of the Indo-Aryan word *ása* (old Persian, *arta*), which has been variously interpreted as meaning 'a regular order in general', 'moral rectitude', 'a true law of the universe' and so on.[b] This *ṛta* which is responsible for the orderly functioning of universal laws such as the fixity of the stars, the movements of celestial bodies, etc., also controls matters terrestrial and spiritual, including the orderly or disorderly functioning of bodies of human beings on the earth. The beginnings of a plant science have been traced in stray references to external and internal structures of plants, some physiological processes involved in manuring, plant classification and evolution. Regarding agriculture, trade and industry, Winternitz mentions that barley used to be cultivated, cattle-rearing formed the main source of income, horse was highly prized and harnessed before the chariot in war and peace, and woodworkers, cabinet and chariot makers, metal workers, shipbuilders and so on formed the main backbone for what passed for industries in Vedic

[a] *ṚV.*, X. 39.3.5.

[b] Filliozat (2), p. 76 (French version).

times.[a] No less important are the philosophical hymns enquiring about the origin of things and of a creator who is variously named as Prajāpati, Bṛhaspati, Viśvakarman, and 'the One'.

The Sāmaveda

The *Sāmaveda* is an anthology of the *Ṛgveda.* The *Saṃhitā* has come down to us in three recensions or schools, e.g. those of the Kauthumas, the Rānāyanīyas and the Jaiminīyas or Talavakāras. It is a collection of both songs and verses. The majority of the verses are borrowed from the *Ṛgveda,* although these are often marked by variations of a linguistic character or those due to exigencies of musical adaptations. A source book of great importance for the study of the most ancient history of Indian music, the *Sāmaveda* and its *Brāhmaṇas* and *Sūtras* are also full of interest from the viewpoint of calendrical astronomy because of their fuller treatment of *gavām ayana,* the *sattras* of various durations and other ceremonies built round the daily progress of the sun. As a derivative work, the *Saṃhitā* naturally enough offers no clue towards the determination of its date except that it is posterior to the *Ṛgveda.*

The Yajurveda

As a compendium of sacrificial formulas, the *Saṃhitā* of the *Yajurveda* came to be developed in a large number of schools of Adhvaryu priests and recensions. Although Patañjali, in the introduction to his *Mahābhāṣya,* mentions 100 schools of the *Veda* of the Adhvaryus, works of the following five schools have come down to us: (*a*) the *Kāṭhaka* or, more correctly, the *Carayanīya-Kaṭha-Saṃhitā,* representing the main recension of the *Kaṭha* school; (*b*) the *Kapiṣṭhala-(Kaṭha)-Saṃhitā,* representing another recension of the same *Kaṭha* school, preserved only in fragments; (*c*) the *Maitrāyaṇi-Saṃhitā,* of the Maitrāyaṇīya school; (*d*) the *Taittirīya-Saṃhitā,* of the Taittirīya or, more particularly, the Āpastamba school; and (*e*) the *Vājasaneyī-Saṃhitā,* after the teacher Yājñavalkya Vājasaneya, in the recensions of Kanva and Madhyandina.

Traditionally, the works of the first four schools are grouped under the *Black Yajurveda* and the last *Saṃhitā* belongs to the *White Yajurveda,* but both the groups, on the whole, deal with common materials. As to their relationship to the *Ṛgveda,* both the groups and their recensions abound in *mantras* borrowed from the *Ṛgveda,* with, however, many and profound variations. The chief difference between the *Black* and the *White Yajurveda* lies in the fact that, in the former, the *mantras* are followed by, and often intermingled with, theological discussions and explanations, in prose, called *Brāhmaṇas,* whereas, in the latter, the *mantras* are carefully separated from the *Brāhmaṇas* and the materials treated in a more systematic manner.

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[a] Winternitz, I, pt. I, pp. 55–57.

From the geographical data embedded in these texts, it appears that the *Kaṭha-Kapiṣṭhala* school flourished in Kashmir and the Panjab and the *Maitrāyaṇīya* school in Gujarat, the *Taittirīyas* had their largest number of adherents in South India from where Āpastamba and Baudhāyana came and the sphere of activity of the Vājasaneyins was confined largely in north-eastern and eastern parts of India.[a] Such a distribution of spheres of influence of the various Yajus schools was, however, by no means water-tight, for there exists clear evidence of the Kaṭha and the *Taittirīya* schools operating in the Madhyadeśa as well.

The verses or *ṛcas* which occur in the various recensions of the *Yajurveda* are also found in the *Ṛgveda*, with the difference that the whole hymns of the latter are rarely incorporated in the former. As Winternitz has pointed out, the *Yajurveda* used only single verses, 'torn from their context, which just appeared suitable to some sacrificial ceremony or other...' There is hardly any ground for doubting that the various recensions of the *Yajurveda* are posterior to the *Ṛgveda* and that the *Saṃhitās* of the *Kāṭhaka, Kapiṣṭhala, Maitrāyaṇī* and *Taittirīya* schools are older than the *Vājasaneyī Saṃhitā*.

The importance of the *Yajurveda* texts as possessing several passages of considerable astronomical significance need hardly be overestimated. While the *nakṣatras* are doubtless mentioned in the *Ṛgveda*, their whole series numbering 27 or 28 and headed by *Kṛttikās* turn up for the first time in the recensions of the *Yajurveda*. The *gavām ayana* and the *sattras* resembling those already given in, and probably taken over from, the *Sāmaveda* and its *Brāhmaṇas*, find lengthy treatment in these *Yajus* texts. Traces of mathematical knowledge are reflected here and there in the enumeration and naming of large numbers in multiples of ten, cases of addition, subtraction and multiplication, fractions first noticed in the *Ṛgveda* and further developed in the *Maitrāyaṇī Saṃhitā*, and progressive series.

From the point of view of medicine, the *Yajurveda* texts also contain information of importance, though not much different from other *Saṃhitās*, except of course the *Atharvaveda* about whose importance in relation to medicine we shall say more in what follows. Rudra who is represented in the Vedic literature as one possessing great strength and power and as the cause of terror is described in the *Yajurveda* as the first divine physician—*prathamo daivyo bhiṣak*.[b] This idea is also found in the *Ṛgveda* where this terror-inspiring Rudra is also famed as the best of all physicians.[c] About the different diseases, the *White Yajurveda* mentions 100 types of *yaksmā*, including the *rājayaksmā* and the legend of Soma, the moon being afflicted by the disease.[d] Of the anatomical nomenclature compiled by Filliozat[e] from the various Vedic *Saṃhitās*, several are found in the *Yajurveda* and its *Brāhmaṇas*. The pathological relationship of bile (*pitta*) with *agni* is

[a] Keith (2), p. xciii.
[b] *Taitt. S.*, IV. 1.2; *Vāj. S.*, XVI. 5.
[c] *ṚV.*, II. 33.4.
[d] *YV.*, XII. 97; *Taitt. S.*, II. 3.5.2.
[e] Filliozat (2), pp. 121–28 (French version).

attested in both the *Atharvaveda* and the *Yajurveda*.[a] A large number of plant remedies are recommended for curing diseases in the various recensions of the *Yajurveda*. In this connection important references to plant structures, physiology and classification are also met with in this *Saṃhitā*.

The Atharvaveda

The *Atharvaveda* comprises 731 hymns and about 6,000 verses grouped under 20 books of which the first eighteen form the *Atharvaveda* proper and the last two supplementary additions of comparatively recent date. Its borrowings from the *Ṛgveda* are considerable, as much as one-seventh deriving without variation from the *ṛcas* belonging to books X, I and VIII. But quite a large number of the verses are original and bear marks of great antiquity. At the time of its taking shape, the Vedic Indians had already penetrated to the south-east and settled down in the Gangetic plains, as evidenced by the mention of a tiger-skin as symbol of royal power.[b] Society also became differentiated into four castes with the Brāhmaṇas claiming the highest privileges.

The oldest name of this fourth *Veda* was probably *Atharvāṅgirasaḥ*. The frequent separation of this compound word and the mention of the *Veda* by each name show 'that the compound is not a congealed formula, but that the texts are conscious of the fact that each has a distinct individuality, a right to separate existence.'[c] Originally, both the words '*atharvan*' and '*aṅgiras*' meant fire-priest, the fire-cult playing an important role in the daily life of the Indian people in much the same way as it did in the case of the ancient Persians. The two terms further signified two different species of magic formulas; the *atharvan* referred to holy magic bringing about happiness and the *aṅgiras* to hostile sorcery or black magic.

The Atharvan songs and spells concerning healing of diseases throw important light on the oldest system of Indian medical science. Through these charms and spells the symptoms of a large number of diseases are described with great clarity. Winternitz notices a remarkable similarity between the magic incantations of the Indians and those of old Germans in the fact that while the *Atharvaveda* mentions 55, 77, or 99 diseases, German incantations often refer to 77 or 99 diseases.[d] Another peculiarity of the *Atharvaveda* consists in its recognition of worms as the causes of many diseases. Descriptions given of these worms are also of considerable zoological interest. The *Atharvaveda* is also very rich in anatomical nomenclature as will be clear from a glance at Filliozat's list mentioned previously.

Opinion is divided on the question of origin of the theory of *tridoṣa* or *tridhātu* in the *Atharvaveda*. But the physiological role of air or *prāṇa* as an organic and cosmic force is well attested in the *Saṃhitās*, including

[a] *AV.*, XVIII. 3.5; *Vāj. S.*, XVII. 6; *Kāth. S.*, XVII. 17.
[b] Winternitz, I, pt. I, p. 108.
[c] Bloomfield, p. xviii.
[d] Winternitz, I, pt. I, p. 115.

the *Atharvaveda*. This point is important from the point of view of the evolution of the pneumatic theory, its maturity in later Āyurvedic texts and the parallelism noticed in some Greek texts such as one treatise on this subject by Hippocrates and Plato's *Timaeus*.

The *Atharvaveda* offers little assistance towards our understanding of the nature and extent of the Vedic astronomy. Nevertheless, it does contain stray passages of astronomical consequence, such as the solar eclipse, the mention of *rāhu* for the first time, intercalation with a thirteenth month and similar titbits. Its late nineteenth book reproduces the list of 28 *nakṣatras* including *Abhijit*.

Finally, its cosmogonic and philosophical hymns belonging doubtless to the latest parts of this *Veda* are of no less importance to the history of Indian science. In 63 hymns addressed to goddess earth, a specimen of good ancient poetry, Mother Earth is described with all her physical geographical peculiarities as the supporter and preserver of life. Likewise, time (*kāla*) is recognized as the first cause of all existence. Time is ageless, begot the yonder heaven and the earth, then the waters, the *brahma*, the *tapas* and the regions of space and so on.

The Brāhmaṇas

The *Brāhmaṇas*, the second great division of the Vedic literature, have been styled by Winternitz as the 'Science of Sacrifice'. Eggeling, in his introduction to the *Śatapatha Brāhmaṇa*, has traced the genesis of this class of literature to the gradual dispersal of the Brāhmaṇa communities from the Panjab to the eastern and southern parts of the country and to the necessity of dividing sacrificial duties among different classes of priests, namely the Hotār, the Udgātar, the Adhvaryu (the performer of the actual sacrificial acts) and the Brāhmaṇa or high priest.

The beginnings of such theological elucidations may be seen in the *Saṃhitās* of the *Black Yajurveda* where the *mantras* as a rule are either followed by, or intermingled with, their dogmatic explanations to constitute the *Brāhmaṇa* portion which thus developed into a convenient textbook for the Adhvaryu priest. This might have stimulated concurrently the compilation of *Brāhmaṇa* texts for the Hotār and the Udgātar priests. The Vājasaneyins who came later obviously profited by the experience of the older schools and from the beginning separated the *Brāhmaṇa* from the carefully selected *mantras* and arranged the whole literature in a highly systematic manner. The principal *Brāhmaṇas* which thus came to be attached to the different *Saṃhitās* are enumerated below:

Saṃhitā	*Saṃhitā* *Schools and recensions*	*Brāhmaṇas*
Ṛgveda	*Sakala*	*Aitareya*
	Vaskala	*Kauṣītaki* or *Sāṅkhāyana*
Sāmaveda	*Kauthuma* } *Rāṇāyanīya* }	*Pañcaviṃśa* or *Tāṇḍamahā* : *Ṣaḍviṃśa*
	Jaiminīya	*Jaiminīya*

Saṃhitā	*Saṃhitā*	*Brāhmaṇas*
Yajurveda	Black: *Kāṭhaka-*	*Kaṭha-* fragment
	Kapiṣṭhala	
	Maitrāyaṇī	
	Taittirīya	*Taittirīya*
	White: *Vājasaneyī*	*Śatapatha*
Atharvaveda		*Gopatha*

If the *Brāhmaṇas*, in the course of their theological disputations, sought to throw a great deal of light on the earliest metaphysical and linguistic speculations and indulged in many mythological fabrications around the substance of the hymns and verses of their respective *saṃhitās*, they did not fail to do so with respect to matters scientific. In this way many astronomical, anatomical, pathological, physiological ideas and concepts, and information regarding plant and animal life assumed clearer perspective through Brāhmaṇic interpretations.

The Āraṇyakas-Upaniṣads

The third division of the Vedic literature comprises the *Āraṇyakas* (forest texts) and the *Upaniṣads* (secret doctrines), which arose out of the *Saṃhitās* and the *Brāhmaṇas* of the different Vedic schools. The *Aitareya-Āraṇyaka* which includes the *Aitareya Upaniṣad* is part of the *Aitareya Brāhmaṇa* and likewise the *Kauṣītaki Āraṇyaka-Upaniṣad* represents the concluding portions of the *Kauṣītaki Brāhmaṇa*. The *Pañcaviṃśa Brāhmaṇa* ends in the *Chāndogya Upaniṣad*, of which the first section is an *āraṇyaka*. The *Jaiminīya* and the *Kena Upaniṣads* belong to the Jaiminīya or Talavakāra schools of the *Sāmaveda*. The *Upaniṣads* of the *Black Yajurveda* schools include the *Taittirīya Āraṇyaka-Upaniṣad*, a continuation of the *Brāhmaṇa* bearing the same name and the *Mahānārāyaṇa*, the *Kaṭha* or *Kāṭhaka*, the *Śvetāśvatara*, the *Maitrāyaṇī Upanisads*. The greatest and the most important of all *Upaniṣads* is the *Bṛhadāraṇyaka* which belongs to the *Śatapatha Brāhmaṇa* of the *White Yajurveda*. The *Īśā Upaniṣad* forming the last section of the *Vājasaneyī Saṃhitā* is short but valuable. The *Muṇḍaka* and the *Praśna Upaniṣads* are offshoots of the *Atharvaveda.*

The six of the above-mentioned *Upaniṣads*, viz. the *Aitareya*, the *Bṛhadāraṇyaka*, the *Chāndogya*, the *Taittirīya*, the *Kauṣītaki* and the *Kena*, which, in language and style, resemble the *Brāhmaṇas*, represent the earliest stage of development of this type of literature whose antiquity cannot be far different from that of the *Brāhmaṇas.*[a] The *Kaṭha*, the *Śvetāśvatara*, the *Mahānārāyaṇa*, the *Īśā*, the *Muṇḍaka* and the *Praśna* which also contain the Vedānta doctrine are in all probability pre-Buddhistic. The *Maitrāyaṇī Upaniṣad* in which the Vedic prose is no longer traceable is of a much later date and possibly post-Buddhistic.

Besides the *Upaniṣads* mentioned above, some 200 texts bearing the title of this class and attributed to one or the other of the Vedic schools

[a] Winternitz, I, pt. I, p. 206.

have come down to us. Most of them having no connection with the *Veda* are akin to the *Purāṇas* and the *Tantras* and belong to a much later date.[a] Of these several non-Vedic *Upaniṣads*, mention may be made of the *Subala Upaniṣad*, frequently referred to by Rāmānuja and the *Garbha Upaniṣad*; the former deals with metaphysics, cosmology, physiology and other matters, whereas the latter, as the title implies, is an embryological text having some importance in the history of medicine.

Written in the form of dialogues often reminding us of Plato, the *Upaniṣads* are primarily important as repositories of physical concepts concerning both the organic and the inorganic world. A sharp distinction is made between these two worlds—a distinction which, in the view of Deussen, dominates the Indian view of nature also.[b] Organic bodies such as gods, men, animals and plants are in essence the *ātman* itself and are regarded as wandering souls. Inorganic bodies called *mahābhūtāni*, although controlled by *Brahman*, are not wandering souls, but only the stage, the material substratum enabling the souls to play their part. Embedded in this concept of *mahābhūtāni* is the idea of five elements whose gradual evolution from water as the only primordial element into earth, water, fire, wind and ether as the five *mahābhūtāni* is traceable in the *Upaniṣads*.

The *Upaniṣads* tacitly assume that, like the macrocosm, the microcosm represented by the human body is also constituted of the five elements. Some physiological concepts applicable to man, animals and plants as also some elementary principles of classification are met with. Astronomical conceptions are only slightly developed and do not go beyond what we find in the two other preceding divisions of the *Veda*. In the simple cosmography preached by the *Upaniṣads*, the earth is surrounded by water and has oceans, mountains and seven island continents. The heaven and the earth form two halves of the egg of the universe, a recurrent conception throughout the Vedic literature.

Chronology of the Vedic Literature

The chronology of the Vedic literature has always been, and is even now, a matter of great difficulty and controversy. Considering that the whole of the Vedic literature must be pre-Buddhist and the *Sūtra* works synchronous with the origin and spread of Buddhism, Max Müller suggested the period between 600 and 200 B.C. for the development of the *sūtras*, the period between 800 and 600 B.C. for the development of the prose style of the *Brāhmaṇas* and *Āraṇyakas-Upaniṣads* and the period 1000 to 800 B.C. for the compilation of the *Saṃhitās*, of which the poetry part or the *mantras* probably originated in the period between 1200 and 1000 B.C.[c] In his views, the oldest of the *Vedas*, the *Ṛgveda*, could not have been

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[a] Winternitz, I, pt. I, p. 208.
[b] Deussen, p. 186.
[c] Winternitz, I, pt. I, p. 225; Max Müller (1), pp. 23 ff.

composed earlier than 1200 B.C. Leopold von Schroeder[a] suggested a much earlier date, 1500 or even 2000 B.C., for the *Ṛgveda*, while Hermann Jacobi[b] and B. G. Tilak,[c] on astronomical grounds, tried to date the beginning of the Vedic literature in the third millennium B.C. The period around 1400 or 1500 B.C. for the formulation of the earliest Ṛgvedic hymns has found a strong support from the clay tablets discovered in Boghazköi, the capital of the ancient Hittites who had as their deities some of the common Vedic gods such as Mitra, Varuṇa, Indra and Nāsatyau.[d] From an analysis of different studies on the Vedic chronology Winternitz concluded, and this view is now generally followed, that 'we shall probably have to date the beginning of this development about 2000 or 2500 B.C. and the end of it between 750 and 500 B.C.'[e]

THE *VEDĀṄGAS*, THE *SŪTRAS* AND THE ORIGIN OF SANSKRIT SCIENTIFIC LITERATURE

We now come to another important group of literature, the *Vedāṅgas*, which deal separately with six special branches of knowledge, viz. phonetics (*śikṣā*), ritual (*kalpa*), grammar (*vyākaraṇa*), etymology (*nirukta*), metrics (*chandaḥ*) and astronomy (*jyotiṣa*).[f] These branches of study arose within the Vedic schools themselves as a necessary condition for mastering the *Vedas*. Being works of human specialists, these are called *Vedāṅgas* or auxiliary sciences of the *Veda*.

The Sūtra Style

Their authors adopted in general the *sūtra* or the highly condensed aphoristic style intended to sum up only the pith of the learning in short sentences generally using nouns often compounded at great length and avoiding the use of verbs as far as possible. The main purpose was to facilitate easy memorization of a vast body of ritualistic and other materials. From the point of precision and brevity, Winternitz thinks that 'there is probably nothing like these *sūtras* of the Indians in the entire literature of the world'.[g] The style became so dominant a feature that this was adopted without question by the various philosophical schools, the grammarians, phoneticians, specialists on metrics and by the writers of the *arthaśāstra*, the *kāmaśāstra*, the *nāṭyaśāstra* and so on.

On account of great economy of words and the avoidance of verbs, the *sūtras* always remained enigmatic except to the initiated. For this reason another literary style, the *bhāṣya*, had to be developed, which aimed at

[a] Schroeder, pp. 291 ff.
[b] Jacobi (1), p. 158.
[c] Tilak, pp. 40 ff.
[d] Giles, pp. 64–66.
[e] Winternitz, I, pt. I, p. 271.
[f] *Muṇḍ. Up.*, I, 1.5.
[g] Winternitz, II, p. 235.

elucidating the *sūtras*, sometimes in the form of a dialogue between the teacher and the student. In this style, often the opposite views are first brought in, their insufficiencies explained and the true solutions given at the end. The service rendered to the development of this form of writing by the great *bhāṣyakāras* like Patañjali, Vātsyāyana and Śaṅkara, to mention a few, need hardly be overestimated.

If the *sūtras* necessitated the *bhāṣyas*, they also no doubt paved the way for the development of the *śloka* form of composition adopted in the *Dharmaśāstras*, medical texts, mathematical and astronomical works, encyclopaedic treatises like the *Bṛhatsaṃhitā* and in arts and sciences in general. The main advantage of this form is that it is easy to write and memorize and therefore readily appeals to the scholar. One comparatively simple meter commonly followed in scientific compositions is the *Āryā*, although more complex meters are also used.[a] After the development of these different styles of composition, several authors tended to use one or more of them simultaneously in their works, of which the medical *saṃhitās* are convenient examples.

Of the various *vedāṅgas* mentioned, we may leave aside the phonetics largely concerned with the rules of pronunciation, but others contain matters of scientific importance.

The Kalpasūtras

The *Kalpasūtras* are available in four different classes, e.g. the *Śrauta*, the *Gṛhya*, the *Dharma* and the *Śulba*. As the materials of the *Saṃhitās* and the *Brāhmaṇas* constitute the basis of these *sūtras*, passages in them of scientific import have received fresh treatment and sometimes further elaboration at the hands of the *sūtrakāras*. Such is particularly the case with regard to the Vedic calendars which have received lengthy treatment in the *Lāṭyāyana Śrautasūtra* and the *Nidānasūtra* of the *Sāmaveda*. The fourth class of the *Kalpasūtras*, the *Śulbasūtras*, are often attached to the *Śrautasūtras* and are important as the oldest Indian works on geometry, irrational numbers and other mathematical topics.

The *Mānava Dharmaśāstra* or the *Manu Smṛti* and later *smṛtis* originated from the *Dharmaśāstras*, one of the four great divisions of the *Kalpasūtras*. The mythical Manu is mentioned in the *Taittirīya Saṃhitā* and by Yāska; Aśvaghoṣa's references agree in part with some of the teachings of the *Manu Smṛti*; and finally the epic *Mahābhārata* preserves a considerable portion of it. Obviously, the form in which we now have it developed over a long period of time, and it may be placed anywhere between 200 B.C. and A.D. 200.[b] As a law book dealing with all aspects of human life, it occasionally furnishes information of scientific value relating to botany, zoology, agriculture and the like. This work expressing as it does the soul and the philosophy of life of a large section of the ancient Indian

[a] Keith (3), p. 409.

[b] Keith (3), p. 441.

people is comparable to Lucratius' great poetical work.[a] Mention may also be made of the *Yājñavalkya Smṛti* (*c.* A.D. 300) which, although a treatise on law, deals at length on embryology and the development of the human body.[b]

The Yajurvedins were the most active and prolific producers of this kind of literature. Among them again the Taittirīya school had an overwhelming leadership. Baudhāyana, Āpastamba and Hiraṇyakeśin of the Taittirīya school composed works on all the four departments of the *Kalpa-sūtras*, whereas Vādhūla, Bharadvāja and Vaikhānasa covered between two and three such departments. Similar services on a much reduced scale were rendered by Mānava and Vārāha for the Maitrāyaṇī school and by Kātyāyana for the Vājasaneyī school.

Although it is certain that the *sūtras* were composed after the period of the main literary activity in preparing the *Saṃhitās*, the *Brāhmaṇas* and the *Upaniṣads* was over, that is after 700 or 600 B.C., serious difficulties arise as soon as the dating of the *sūtra* literature is attempted. From a consideration of the tradition of the Vedic schools as well as from internal evidence, Baudhāyana and Mānava are older than Āpastamba, and Āpastamba must have flourished before Pāṇini, Kātyāyana and Patañjali. Pāṇini's date is itself debatable and is no better datable than most of the ancient texts of this kind. Nevertheless, scholars are generally agreed that Pāṇini lived in the fourth century B.C. (*c.* 350 B.C. according to Keith), that Kātyāyana may be placed around *c.* 250–200 B.C. and that Patañjali who refers to a sacrifice for Puṣyamitra (reigned from *c.* 185 or 178 B.C.) most probably wrote his *Mahābhāṣya* about 150 B.C.[c] On the basis of Pāṇini's date, George Bühler was inclined to place Āpastamba 150 to 200 years earlier, which gives his date as *c.* 500 to 550 B.C. Keith is not, however, prepared to place Āpastamba beyond *c.* 350 B.C.[d] For Baudhāyana's date Keith's estimate is fifth century B.C. If Bühler's estimate for Āpastamba is correct Baudhāyana may be dated as *c.* 600 B.C.

Grammar, Lexicography and Metrics

The *Prātiśakhyas* which are works on phonetics attached to the different *Vedas* bear testimony to the beginnings of grammatical studies in India. Yāska (*c.* 500 B.C.), the celebrated author of the *Nirukta*, refers to schools of grammarians. Unlike the lexicographers, the grammarians were more concerned with the language, both written as well as spoken. Although a long line of grammarians must have existed before Pāṇini (*c.* 350 B.C.), his *Aṣṭādhyāyī* possibly rendered obsolete the efforts of his predecessors. Written in 4,000 short *sūtras*, the work deals with technical terms, nouns in composition and case relations, rules for adding suffixes to the roots and so on, always from the point of view of the language and using it correctly in composition.

[a] Keith (3), p. 443.
[b] Choudhury, pp. 52–60.
[c] Renou and Filliozat, pp. 86–91; Keith (3), pp. 426–28.
[d] Keith (2), Preface, clxxi, xlv, clxxii.

Kātyāyana (*c.* 250–200 B.C.) wrote the *Vārttika*, an independent work in which Pāṇini is often criticized for inaccuracies. Patañjali's *Mahābhāṣya* (*c.* 150 B.C.) is not only a grand commentary on the *Aṣṭādhyāyī*, but contains refutations of Kātyāyana's views and additional matters based on the works of other grammarians to which no doubt he had access. These grammatical works and expositions are a veritable source of information of many scientific and technical subjects as will be seen in the various chapters of the book.

Yāska's *Nirukta* is derived from the ancient *nighaṇṭavas*, that is lexicographical works containing Vedic terms. Other well-known lexicons from which citations have come down to us include Kātyāyana's *Nāmamālā* and Vyāḍi's *Utpalini*. The most important and exhaustive lexicographic work that we now possess is the *Nāmaliṅgānuśāsana* of Amarasiṃha, better known as *Amarakośa*. Amara was a Buddhist and a poet who probably lived in the sixth century A.D.,[a] although Keith would place him after the eighth century.[b] The scientific importance of the work will be apparent from the fact that the first section gives names for sky, celestial space (atmosphere, planets and stars), regions, divisions of time, phases of the moon, eclipses, denizens of the underworld (serpents, poison). The second section deals with terrestrial matters—oceans, fishes, animals, human beings, their anatomical peculiarities, diseases, plants and forests, agriculture and commerce, geographical information, including stone quarries and mines and diverse matters. The third section which contains about 13,000 terms gives epithets, different names, homonyms, invariant words, in a semantic arrangement which served as a model for later lexicographers. It is noteworthy that several botanical terms and names of medicinal plants further enrich this great lexicon. Renou and Filliozat observe that the *Agnipurāṇa* is more or less an abridged form of the *Amarakośa*.

The Vedic interest in meters is reflected in certain sections of the *Ṛk-Prātiśākhya*, Kātyāyana's *Anukramaṇi*, the *Nidānasūtra* and other works. But a treatise dealing exclusively with the science of meters as used in the Vedic texts is the *Chandaḥsūtra* of Piṅgala (*c.* 200 B.C.) which has come down to us with the commentary of Halāyudha (the tenth century A.D.). Piṅgala uses algebraic symbols, say l and g, to denote short and long syllables respectively as well as groups of three syllables to serve as the basis of metrical ending, e.g. $m = — — —$, $y = \cup — —$.[c] The text shows acquaintance with about 160 different types of meters. The text is also important mathematically as it deals with Pascal's triangle (*meru-prastāra*) and reveals knowledge of binomial theorem.

Discussions on meters are also found in the *Nāṭyaśāstra*, the *Agnipurāṇa*, and the *Bṛhatsaṃhitā*. Of works on metrics of later periods, mention may be made of Janāśraya's *Chandoviciti*, Gaṅgādāsa's *Chandomañjarī* and Kṣemendra's *Suvṛttatilaka* (the eleventh century A.D.).

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[a] Renou and Filliozat, pp. 100–1.
[b] Keith (3), p. 413.
[c] Renou and Filliozat, p. 104; *see also* Keith (3), pp. 415–16.

Jyotiṣa

As a *Vedāṅga*, the science of astronomy (*jyotiṣa*) is available in the recensions of the *Ṛgveda* and the *Yajurveda*, but containing the same materials. As an astronomical text, this will receive further treatment in the chapter on astronomy. The text is dated *c.* 400 B.C.,[a] but the astronomical elements taught therein, the positions of the equinoxes that can be deduced from clear statements, belong to the period of the *Saṃhitās* and the *Brāhmaṇas*.

THE PHILOSOPHICAL *SŪTRAS* AND *BHĀṢYAS*

We have seen how the philosophical ideas already embedded in the *Saṃhitās* and the *Brāhmaṇas* were sorted out to initiate a new kind of disputation and develop a new type of literature which culminated in the *Upaniṣads*. During the *sūtra* period, we notice the advent of different philosophical schools adhering to definite opinions and giving expressions to them in the *sūtra* style of writing. The doctrines summed up in these *sūtras* are described by the term *darśana* which literally means 'views' or, in other words, 'points of view', 'systems', etc. Several writers have enumerated the prevalent philosophical systems differently, but we may here distinguish between the orthodox systems of the Brāhmaṇas theoretically based more or less on the authority of the *Vedas* and the unorthodox systems represented by the Buddhists and the Jaina schools and by the materialistic schools of the Nāstikas, the Lokāyatas and the Cārvākas. As the Buddhist and the Jaina schools will be referred to under source materials dealing with the Buddhist and the Jaina literature, we shall be concerned here largely with the orthodox systems, making a passing reference to the literature of the materialists.

The orthodox systems are traditionally recognized to be six, which are paired in three groups on account of certain fundamental affinities and agreement between the two members of the pair. These are: the *Pūrvamīmāṃsā* and the *Uttaramīmāṃsā* or the *Vedānta*; the *Sāṃkhya* and the *Yoga*; and the *Nyāya* and the *Vaiśeṣika*. Jacobi expressed the view that the orthodox systems were in all probability codified between the second and the fifth century A.D. during the grand period of spiritual and intellectual activity accentuated by the invasions followed by the rise of the Gupta power.[b] He, however, conceded that the *Sāṃkhya*, the *Yoga*, and the *Lokāyata* might have been developed by 300 B.C. on the evidence of Kauṭilya's *Arthaśāstra* in which, under the term *ānvīkṣikī*, these three systems are clearly mentioned. The *Nyāya* and the *Brahmasūtra* were probably composed before the formulation of the Buddhist *Vijñānavāda* between A.D. 200 and A.D. 450. The *Pūrvamīmāṃsā* and the *Vaiśeṣika*

[a] Renou and Filliozat, p. 178.

[b] Jacobi (2), p. 2; (4), p. 270.

might have been composed a little earlier. Keith sums up by saying that between the dates of the principal *Upaniṣads* and the third or the fourth century A.D. these different philosophical systems then under active investigation took their final forms.[a] Dasgupta disagreed with such late dating of the philosophical *sūtras*, as we shall see when we take up the question of dates of the individual *sūtras*.

Renou and Filliozat hold that the origin of the speculation constituting the systems is much older than what is implied in Jacobi's investigations. It is quite possible that the activity of the Buddhism, by creating an opposite reaction among the Brāhmaṇas to defend and strengthen their position, indirectly contributed to the codification of their philosophies.[b] The speculations of logic possibly developed partly in the medical schools.

The Mīmāṃsā

To start with the *Mīmāṃsā* (investigation), the term appears in all the Vedic literature since the *Yajur-* and the *Atharva-veda*. The word is used in the *Dharmaśāstra*, Pāṇini knows it and Patañjali in his *Mahābhāṣya* speaks of the Mīmāṃsakas. Kātyāyana's *Vārttika* on certain points agrees with the phraseology of the *Mīmāṃsāsūtra*. The original *sūtras* are attributed to Jaiminī about whose personality nothing authoritative is known and who in all probability was a mythical personage like the founders of other *darśanas*. Dasgupta,[c] however, thinks that the *Mīmāṃsāsūtra* was probably written about 200 B.C. The *Mīmāṃsāsūtra* was commented upon by Sabarasvāmin (fifth century A.D.) and later on by Prabhākara (*c.* A.D. 600) who wrote the *Bṛhatī* and by Kumārila (*c.* A.D. 700), the author of the *Ślokavārttika*.[d] For the history of science, the Mīmāṃsakas hold an important position through their interpretation of sound and its propagation, which is different from that of the Vaiśeṣikas.

The Sāṃkhya

The term *sāṃkhya* which first appears in the *Śvetāśvatara Upaniṣad* literally means that which concerns the number and appropriately so inasmuch as it frequently resorts to enumeration, categorization and hierarchical classification. More generally, however, it also signifies the theory, reflection, etc., as opposed to practice implied in the *Yoga*. The first striking fact about the *Sāṃkhya* doctrines is that these are non-Brāhmaṇic in the sense that their bases are not to be found either in the Vedic rituals or in their beliefs and teachings. This led to one theory of its origin outside the sphere of the Vedic influence, possibly in the same regions which witnessed the beginnings of the Buddhism.[e] In fact, the majority of scholars—Senart, Jacobi, Garbe, Pischel and, with certain reservations,

[a] Keith (3), p. 472.
[b] Renou and Filliozat, p. 2.
[c] Dasgupta, I, p. 370.
[d] Keith (3), pp. 473–74; Renou and Filliozat, p. 10.
[e] Renou and Filliozat, p. 34.

Oldenberg—admitted that at a certain point of time the *Sāṃkhya* did form the philosophical basis of the Buddhism. Garbe was convinced about the influence of the Kṣatriyas on the development of the system in its primitive form, which later on veered to orthodoxy.[a] Keith and some other scholars, on the other hand, believe in the Upaniṣadic origin of the *Sāṃkhya*, the latter's conception of the three *guṇas* deriving from the former's three elements: water, fire and earth.[b] On the basis of the derivation of Buddhism from the *Sāṃkhya*, Winternitz suggested that the philosophy had been in existence since 800–550 B.C.[c]

The *Sāṃkhya* ideas in their various forms, primitive or more developed, are met with in a variety of literature of which mention may be made of the *Buddhacarita*, the *Mahābhārata* (*mokṣadharma*), the *Purāṇas* (*Brahma* and *Viṣṇu*), the *Dharmaśāstra*, the *Caraka Saṃhitā* and in some Tāntric and Āgama literature. Kauṭilya's reference to *Sāṃkhya* has already been mentioned. This itself explains the importance of the system in influencing the development of physical concepts about the material world, medical theories and in many other spheres.

The historicity of Kapila mentioned as the founder of the doctrine or of his follower Āsuri has not been proved. We are also on uncertain ground regarding Pañcaśikha, another early exponent of the system. The first text that we possess on the subject is *Sāṃkhyakārikā* by Īśvarakṛṣṇa (fourth century A.D. according to Renou and Filliozat and *c.* A.D. 200 according to Dasgupta).[d] Written in *Āryā* meter, the *Kārikā* is a brilliant piece of philosophical composition which Barth describes as the pearl among the whole scholarly literature of India (*le perle de toute la littérature scholastique de l'Inde*).[e] The *Kārikā* was commented upon by Gauḍapāda (*c.* sixth century A.D.) in his *Gauḍapādabhāṣya* also known as *Sāṃkhyakārikābhāṣya*. In the ninth century A.D., versatile Vācaspatimiśra produced a new commentary on the *Kārikā*, the *Sāṃkhyatattvakaumudī*, which is probably the best work we now have on the subject. The *Sāṃkhyasūtra* also callèd the *Sāṃkhya-pravacana*, traditionally attributed to Kapila, is a work of a much later date (the tenth century A.D.). Aniruddha (*c.* A.D. 1450) commented on the *sūtra* in his *Sāṃkhyasūtravṛtti*, and about two hundred years later, Vijñāna-bhikṣu (*c.* A.D. 1650) composed his *Sāṃkhyapravacanabhāṣya* from the curious standpoint of reconciling the *Sāṃkhya* doctrines with those of the Vedānta.[f]

The Yoga

The *Yogasūtra* is attributed to Patañjali who is different from the author of the *Mahābhāṣya*. The *sūtra* makes reference to the Buddhist *Yogācāra* and may be dated between the third and fifth century A.D. Then there is the *Yogabhāṣya* ascribed to the mythical Vyāsa (sixth century A.D.

[a] Renou and Filliozat, p. 34.
[b] Keith (3), pp. 487–88.
[c] Winternitz, III, pt. II, p. 506.
[d] Renou and Filliozat, p. 36; Dasgupta, I, p. 212.
[e] Renou and Filliozat, p. 36.
[f] Keith (3), p. 489.

according to Winternitz),[a] on which a commentary was written by Vācaspatimiśra under the title *Tattvavaiśāradī*, and by Vijñānabhikṣu in his *Yogavārttika*. The *Yoga* system, particularly its offshoot, the *Haṭhayoga*, teaches principles and practices calculated to promote a healthy body and control and cure many pathological conditions.

The Nyāya

The term *nyāya* variously means 'method', 'rule', 'justice', etc., but philosophically it signifies 'logic' or 'reasoning'. Later it developed itself into some sort of syllogism in five parts. The Indians have been interested in logic from very ancient times, but how ancient it has not been possible to say with any certainty. The term *ānvīkṣikī* (enquiry), the oldest word for philosophy, has also been stretched to mean logic. The founder of the Nyāya system is Gotama, sometimes surnamed Akṣapāda, contemporaneous with Buddha, for which of course no decisive proof exists. But Gotama and Akṣapāda are two different persons, the latter being credited with the redaction of the *Nyāyasūtra* about the third century A.D. An important point in the development of the *Nyāyasūtra* is that similar theories of logic appear in the medical text, the *Caraka Saṃhitā*, which proves the existence of the *Nyāyasūtra* from the beginning of the Christian era or even from pre-Christian times.[b]

Of the large number of commentaries available, the earliest and the most important is the *Nyāyabhāṣya* of Pakṣilasvāmin Vātsyāyana who flourished in the fourth century A.D. and before the Buddhist logician Dignāga. In the beginning of the seventh century A.D., Uddyotakara Bharadvāja wrote his *Nyāyavārttika* to explain the *sūtra* and the *bhāṣya*. Some other important commentaries on the *Nyāya* system include Vācaspatimiśra's *Nyāyavārttikatātparyaṭīkā*, a commentary on Uddyotakara's above-mentioned work, and the *Nyāyasūcinibandha*, an index on the *Nyāya*, Jayanta Bhaṭṭa's (ninth century A.D.) *Nyāyamañjarī*, Udayana's (tenth century A.D.) *Nyāyavārttikatātparyaṭīkāpariśuddhi*, the *Nyāyapariśiṣṭa*, a supplementary work on logic, and the *Nyāyakusumāñjali*, probably the best known of his works. From about the time of Vācaspatimiśra a tendency developed for syncretizing the doctrines of the two allied schools of *Nyāya* and *Vaiśeṣika*, and a large number of *Nyāya-Vaiśeṣika* works in the nature of commentaries began to appear. But before we deal with them we have to say a few words on the origin of the *Vaiśeṣika* system.

The Vaiśeṣika

In the opinion of some historians of ancient Indian thought, the *Vaiśeṣika* system of thinking is considered to be very old. Richard Garbe

[a] Winternitz, I, p. 212; Dasgupta places him in A.D. 400.

[b] Renou and Filliozat, pp. 55–56. S. C. Vidyabhusana dated Akṣapāda's *Nyāyasūtra* about A.D. 150 and believed Gautama's *Nyāya* system as old as 550 B.C. (Dasgupta, I, p. 279).

held it to be anterior to Buddhism, possibly inspiring the Jaina philosophical thinking and definitely preceding the *Nyāya*. The *Vaiśeṣika* is mentioned in several Buddhist texts, e.g. the Milindapānha and the *Lalitavistāra*, and the Jaina text the *Avassaya*.[a] The accounts of the *Vaiśeṣika* found in these texts agree with the *sūtras* that have come down to us from the first century A.D. The *Vaiśeṣika* categories are mentioned in the *Caraka Saṃhitā*. But difficulties arise when we try to date the *Vaiśeṣikasūtra*, traditionally attributed to Kaṇāda, but now believed to have resulted from the efforts of successive generations of philosophers of the same school. Jacobi's preference for a late dating has already been referred to. Suali preferred A.D. 250 to 300, Masson-Oursel A.D. 50 to 150, whereas, in the opinion of Renou and Filliozat, the first century A.D. might be the most acceptable date for the *sūtra*.[b] In the opinion of Dasgupta, 'these *sūtras* are probably the oldest that we have and in all probability are pre-Buddhistic'.[c]

The oldest work based on the Vaiśeṣika teachings, which to all intents and purposes is a new and original exposition and not a commentary, is the *Padārthadharmasaṃgraha* by Praśastapāda who flourished in the fifth century A.D. So great was the importance and authority of this work that the original *Vaiśeṣikasūtra* remained eclipsed for several centuries until it found an able commentator in Śaṅkaramiśra, the author of *Upaskāra* (*c.* 1600). In the meantime, a spate of able commentaries appeared on the *Padārthadharmasaṃgraha*, viz. *Vyomovatī* by Vyomaśivācārya (*c.* ninth century A.D.), the *Nyāyakandalī* by Śrīdhara (tenth century A.D.), the *Kiraṇāvalī* by Udayana (tenth century A.D.), the *Nyāyalīlāvatī* by Vallabhācārya (twelfth century A.D.) and several others.

The syncretization of the two schools which, as already mentioned, started from about Vācaspatimiśra's time is reflected in such works as Bhāsarvajña's *Nyāyasāra* (eighth to ninth century A.D.), Śivāditya's *Saptapadārthī* (*c.* A.D. 950), Śaśadhara's *Nyāyasiddhāntadīpa*, Gaṅgeśa Upādhyāya's *Tattvacintāmaṇi* (thirteenth century), Raghunātha Śiromaṇi's *Padārthatattvanirūpaṇa* (sixteenth century A.D.), Ānnām Bhaṭṭa's *Tarkasaṃgraha* (sixteenth century A.D.) and Viśvanātha's *Bhāṣāpariccheda* and *Nyāyamuktāvalī* (seventeenth century A.D.).

The rationalism of the Nyāya-Vaiśeṣika realists has left its indelible marks on the physical concepts of the ancient and medieval Indians, in the development of atomism, an impetus theory of motion, nature and propagation of sound, classification of plants and animals and their various characteristics, and of a methodology by which to acquire true knowledge.

The Nāstikas, the Lokāyatas and the Cārvākas

The materialistic views of the Nāstikas, the Lokāyatas and the Cārvākas have not survived in independent works, but fragments of them have been preserved for the posterity in the form of refutations of other

[a] Renou and Filliozat, p. 65. [b] Renou and Filliozat, p. 67. [c] Dasgupta, I, p. 282.

schools fundamentally opposed to them. References to diverse atheistical creeds are indeed found in some of the *Upaniṣads*, e.g. the *Chāndogya* and the *Śvetāśvatara*. The *Mahābhārata*, the *Rāmāyaṇa*, the *Mānava-dharmaśāstra* and the *Kāmasūtra* occasionally mention these views. In the *Arthaśāstra*, as already pointed out, the *Lokāyata* is mentioned alongside with the *Sāṃkhya* and the *Yoga* as one of the three divisions of the *ānvīkṣikī*. The most complete exposition of the philosophies of these materialists is to be found in Mādhava's *Sarvadarśanasaṃgraha* (fourteenth century A.D.). Jayanta's *Nyāyamañjari* and Guṇaratna's *Tarkarahasyadīpikā* carry short notices of them; and for similar brief notices the *Ṣaḍdarśana-samuccyaya*, the *Sarvasiddhāntasaṃgraha* and the *Lokatattvanirṇaya* of Haribhadra are also of importance.[a]

Basically opposed to the Vedas and the orthodox philosophical schools, these materialists denied the existence of the soul, considered life and consciousness as products of the combination of matter, did not believe in after life, reward for action, virtue or vice and placed their sole reliance on some sort of Epicurian enjoyment of life. They, however, believed in the four elements of earth, water, air and fire, their atomic character and the formation of the body as a result of their combinations.[b] Likewise, we know of the Ājīvakas led by Makkhali Gosāla, a contemporary of Buddha and Mahāvīra, denying the free will of man and the sophistical school of Ajitakesakambali, holding the *ucchedavāda*, that is the doctrine of annihilation of the individual after death. In the present state of our knowledge, it is not possible to say whether these unorthodox schools of thought had any effect on the progress of science or secular learning.

THE *ARTHAŚĀSTRA*, THE *NĪTIŚĀSTRA* AND RELATED ARTS AND SCIENCES

By the term the *arthaśāstra* is meant the 'science of interests', and as such it includes within its purview all doctrines and manuals which concern the practical aspects of life, e.g. economics, administration, various arts, crafts and techniques, and politics. Nevertheless, the central theme of *arthaśāstra* is politics, which is also treated in a number of manuals under the title of *Nītiśāstra*, *Daṇḍanīti*, *Rājanīti* and so on.

The origin of the subject may be traced to late Vedic times as is evidenced by the use, in the *Hiraṇyakeśi Gṛhyasūtra*, of the terms *dharma*, *artha* and *kāma* representing the three aims of life. That a separate science of *arthaśāstra* had come into existence as a specialized subject of study is attested by the *Smṛtis* of Manu and Yājñavalkya and by the *Mahābhārata*. According to the epic, Bṛhaspati was the founder of this science of polity and might have composed an *arthaśāstra*, but this cannot be the extant *Bārhaspatya-Arthaśāstra* which is a modern manual.[c]

[a] Renou and Filliozat, p. 74.
[b] Dasgupta, I, p. 79.
[c] Renou and Filliozat, p. 125; Keith (3), p. 452.

The Arthaśāstra of Kauṭilya

The most important text that we now possess is the *Arthaśāstra* of Kauṭilya also known as Viṣṇugupta and by the patronymic name of Cāṇakya. A manuscript of the text with a commentary of a small part was first noticed by R. Shamasastry in 1905 and published by him in 1909 in the *Bibliotheca Sanskrita* of Mysore. In view of the great importance of the text, a number of translations and several scholarly studies appeared in quick succession. The work is in prose *sūtra-bhāṣya* style, abounding in obscure technical words of uncertain meaning. Occasionally verses and sometimes *triṣṭubhs* are used; each chapter ends in a few verses summarizing the main points dealt with therein.

The book is divided into 15 *adhikaraṇas* (sections) and 180 *prakaraṇas* (subjects) with a second subdivision into 150 *adhyāyas* (chapters). The length of the text is equivalent to 6,000 *ślokas*. From the point of view of the history of science, special importance attaches to the second *adhikaraṇa*, dealing with the duties of government superintendents. Thus there are superintendents who should be able to differentiate between superior and inferior gems of which detailed scientific descriptions are given (chapter xi). Mining and metallurgical operations involve the supervision of several types of superintendents specialized in mining, metallurgy, minting coins, ocean mining, salt manufacture, etc. (chapter xii). The chapter xii contains much useful information about chemical practices. The chapters xiii and xiv dealing with the duties of the superintendent of gold in goldsmiths' office and state goldsmith contain information on the setting of jewels or glass beads in gold, manufacture of beads with round orifice, making of gold alloys with varying proportions of copper and silver, gold assaying, various methods practised in the adulteration of gold and silver and related matters. Characteristics of good and false balances used in goldsmiths' work are described. In chapter xvii, various kinds of trees constituting the forest wealth are mentioned, giving some information on medicinal plants. A detailed discussion of weights and measures and measurement of space and time with astronomical titbits form the subject-matter of chapters xix and xx. Chapter xxiv is full of interest from the point of view of agricultural practices followed in the time of Kauṭilya. Cattle-rearing, animal husbandry, detailed information on horses and elephants, including their upkeep and uses in war and peace, are described in chapters xxix, xxx, xxxi and xxxii. Classification of land, agricultural meteorology, public health and sanitation and several matters of scientific and technical interest also characterize this unique ancient text. By going through the book, a modern reader will get the impression that science and technology received the fullest possible attention and utilization, through the establishment of several government departments charged with one or many technical subjects, for effectively running the governmental administration. Will it be an exaggeration to say that some kind of a science policy existed in India during the time of the *arthaśāstras*?

Scholarly opinion is divided on the question of the date of Kauṭilya's *Arthaśāstra*. Shamasastry adduced several arguments to prove that Kauṭilya alias Viṣṇugupta alias Cāṇakya, minister of Candragupta, was the genuine author of the *Arthaśāstra*, we now have it, which was accordingly written between 321 and 300 B.C.[a] Jacobi, Meyer, Breloer and others more or less accepted the authenticity of the work as a compilation of the fourth century B.C. Hillebrandt, Jolly, Keith, Bhandarkar, Winternitz and others, on the other hand, believe it to be a work of a much later period, not much earlier than *circa* A.D. 300. Some of Keith's arguments are that the historicity of Kauṭilya has not been proved, Megasthenes makes no mention of him, the *Arthaśāstra* makes no mention of the famous wooden fortifications of Pāṭaliputra, Patañjali does not know the work, the work is posterior to the *Smṛtis* of Manu and Yājñavalkya, but anterior to *Kāmasūtra* (fourth century A.D.).[b]

The Nītiśāstra and Technical Texts

It is quite possible to believe that the various sciences noticed in the *Arthaśāstra* branched off in the course of time to lead to a spate of literature on polity and technical manuals. Kāmandaki's *Nītiśāstra* is a minor work of polity based more or less on the authority of Kauṭilya, but differing in the treatment of the subject-matter. Although some authorities regard Kāmandaki as contemporaneous with Varāhamihira (sixth century A.D.), Keith places the work in *c.* A.D. 700 and Jolly in the eighth century A.D.[c] The work was translated into old Javanese and circulated at one time in Bali. Somadeva's *Nītivākyāmṛta* emphasizes royal duties more from moral aspects than from espionage, cunning and warfare. As we shall see later, the Jainas were also interested in the subject and their great author Hemacandra produced the *Laghu Arhanniti*. The *Śukranīti*, attributed to Śukra or Uśanas, is a much more recent work which deals, among other things, with arts and sciences and mentions gunpowder. Bhoja's *Yuktikalpataru* (eleventh century A.D.) is another interesting work in which we find a good treatment of gems and a chapter exclusively devoted to shipbuilding.

Another curious manual is *Mānasollāsa*, also called *Abhilasitārthacintāmaṇi*, attributed to the Calukya king Somadeva (*c.* A.D. 1131). The work is something like an encyclopaedia treating of education, architecture, music, various sciences, and of course the activities of princes and royal houses. Its fourteenth chapter entitled *matsyavinoda* is important from the point of view of the zoology of fishes. Śrīkumara's *Śilparatna* (sixteenth century A.D.) is largely borrowed from the *Mānasollāsa*.

The architecture (*śilpaśāstra* or *vāstuvidyā*) received more comprehensive and detailed treatment in a number of works that have come down to us. The most comprehensive treatise on the subject is *Mānasāra* (the substances

[a] Shamasastry, Preface, p. vii.
[b] Keith (3), p. 461.
[c] Keith (3), p. 463; Renou and Filliozat, p. 129.

of mensuration) dating from the sixth or seventh century A.D., which has something of the spirit of Vitruvius.[a] Bhojadeva's *Samarāṅganasūtradhāra* (eleventh century A.D.) is another architectural work which gives besides details of several machines. Some passages give us the impression of the existence of an aeronautical science which is probably the result more of imaginary thinking than of serious scientific investigations. To this class of literature belongs the *Yantrasarvasya Yantra*, also of the eleventh century, which has a chapter on *vaimānika prakarana*.[b]

The third aim of life, the fulfilment of *kāma* (love), formed the subject of serious studies in ancient India, of which the most important text that has come down to us is the *Kāmasūtra* (aphorisms on love) of Vātsyāyana Mallanāga of uncertain date. The work is referred to in Kālidāsa's *Raghuvaṃśa* and *Kumārasambhava*, Varāhamihira's *Bṛhatsaṃhitā* and by Bhavabhuti, Subandhu, Māgha and others. These facts, coupled with archaic *sūtra-bhāṣya* style of the *Arthaśāstra* followed in this work, have led Winternitz to suggest its date as the fourth century A.D., while Keith considers A.D. 500 as reasonable.

THE EPICS, THE *PURĀṆAS*, THE POETICS AND THE *BṚHATSAṂHITĀ*

The Epics

The *Mahābhārata*, the epic *par excellence*, is a vast anthology of 110,000 couplets or 220,000 lines in 18 *parvans* plus a supplementary section on the *Harivaṃśa*. The Kurukṣetra or the Bharata battle around which the whole epic is woven might have taken place between 850 B.C. and 650 B.C. although a much earlier date 1400 B.C. has been suggested.[c] According to Winternitz, the extant *Mahābhārata* was compiled over a long period of time extending from 400 B.C. to A.D. 400.[d]

Statements of scientific importance are scattered in the epic and are of a sporadic nature. In astronomy, 12 zodiacal signs, each comprising 2¼ *nakṣatras*, five planets and their motions (*grahacāras*), are mentioned. Information regarding medicine is limited to the functioning of the arteries, circulation of blood through *nāḍis* issuing out from the heart,[e] and the formation of lymph-chyle, blood, flesh, fat, etc.[f] Metals are stated to result from heat and earth matter. Gold concentrations in the earth are of four types, *pipīlikā* (collected by ants), *hiraṇya* (collected from the mountains), *sātakumbha* and *Jāmbunada*.[g] The botanical information comprises the recognition of plants as a living organism made up of five fundamental principles, and endowed with consciousness;[h] their ability to draw water through the roots and force it up with the help of air pressure;

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[a] Renou and Filliozat, p. 131.
[b] Barman Roy, p. 281.
[c] Majumdar (R. C.), I, p. 300.
[d] Winternitz, I, pt. ii, p. 475.
[e] *MB*, III, 179.16; XII, 178.15.
[f] *Harivaṃśa*, 41, 49.
[g] *MB*, III, 185.13; II, 47.4; 133.1; *Harivaṃśa*, 123.3.
[h] *MB*, III, 176; 24, 26; XII, 177.10–17.

plant classification, growth and diseases; classification of flower according to habitat and colour. In zoology, animals are called *trasani* (mobile creature) and are classified into *aṇḍaja, svedaja* and *jarāyuja* which is further subdivided into *grāmya* and *āraṇya.*[a] Statements regarding animal diseases are met with as also the ideas on spontaneous generation of worms and insects.[b] There are also references to cloud formation due to evaporation of water by sun-rays, origin of tide, weaponry, and so on.

The *Rāmāyaṇa,* dated between 200 B.C. and A.D. 200, is another epic of great popularity, which also gives us some idea as to the state of science during the period of its composition and accretion in much the same way as does the *Mahābhārata.* Planets, constellations, zodiac and meteors are mentioned; information regarding metals, liquors, cosmetics and lapidaries is fragmentary; the work abounds in names of trees, herbs, flowers and fruits; zoological information regarding animals, reptiles, fishes, insects and birds is of no small significance as we shall see in the chapter on zoology.

The Purāṇas

According to Amara's definition, the *Purāṇas* are distinguished by five characteristics (*pañcalakṣaṇa*), e.g. creation, recreation, genealogies, cosmic cycles and account of royal dynasties.[c] There are 18 *Mahāpurāṇas,* viz. *Viṣṇu, Mārkaṇḍeya, Brahmāṇḍa, Vāyu, Matsya, Bhāgavata, Kūrma, Bhaviṣya, Liṅga, Padma, Skanda, Brahma Vaivarta, Agni, Bṛhannāradīya, Vāmana, Varāha, Garuḍa* and *Brahma.* The first, third and fourth conform to the five characteristics whereas the rest are not far removed from the *Smṛtis.* There are a large number of *Upapurāṇas.*

As far as sciences are concerned, special importance attaches to the *Viṣṇu,* the *Mārkaṇḍeya,* the *Vāyu,* the *Bhaviṣya,* the *Matsya* and the *Viṣṇu-dharmottara* (a *Upapurāṇa*). The Purāṇic cosmology draws upon the conception of the *hiraṇyagarbha,* the *pradhāna, puruṣa* and *kāla*—ideas already formulated in the *upaniṣads* and other philosophical texts. The *Garuḍa Purāṇa* gives an elaborate account of five pathological categories of diseases[d] and also deals with veterinary science. The *Bhaviṣya Purāṇa* is important from the point of view of zoology, particularly snakes. The *Agni Purāṇa* deals with plant science[e] and also contains reference to zero. In the *Bṛhannāradīya Purāṇa,* the development of trees through different stages are described in some details. The *Purāṇas* have elaborate discussion of the four mundane ages, the *yugas,* some of which were utilized by Brahmagupta and other orthodox astronomers.

Colebrooke (1), Wilson[f] and other scholars dated the *Purāṇas* between the ninth and thirteenth century A.D. On the basis of Kauṭilya's reference

[a] *MB,* VI, 5.10–17.
[b] *MB,* XII, 134.8.
[c] *Amara,* 1.6.5.
[d] Tarkaratna (P.), chs. 150–208.
[e] *Ag. Pu.,* ch. 247, 26–31.
[f] Wilson, I, Preface, xvi.

to the *Purāṇa*, Smith thought that this type of literature had already become authoritative in the fourth century B.C.[a] In his voluminous studies on the *Purāṇas*, Hazra attempted to fix an approximate date of the *Dharmaśāstra* portions of the *Purāṇas* and suggested for the *Mārkaṇḍeya*, the *Vāyu*, the *Brahmāṇḍa*, the *Viṣṇu*, the *Matsya* and the *Bhāgavata* a dating ranging from the third to seventh century A.D. The *Bhaviṣya* may be dated from *c.* A.D. 500 onwards, the *Agni c.* A.D. 800, the *Garuḍa c.* A.D. 900, the *Bṛhannāradīya c.* A.D. 800 and the *Brahma Vaivarta* possibly from *c.* A.D. 700 onwards.

The Poetics

The development of the brilliant literature on poetics, belles-lettres, romantic and historical poetry which frequently indulge in the description of nature and its flora and fauna is outside our scope. Nevertheless, Kālidāsa is of special interest to us, and legend has it that he was one of the nine jewels (Dhanvantari, Kṣapaṇaka, Amarasiṃha, Śaṅku, Vetālabhaṭṭa, Ghaṭakarpara, Kālidāsa, Varāhamihira and Vararuci) who adorned the court of Vikramāditya. This legend has not, however, been taken seriously. It is generally accepted that Kālidāsa flourished after Aśvaghoṣa and during the ascendancy of the Imperial Guptas. His date, though still uncertain, may fall either in the second half of the fourth or in the fifth century A.D.[b] His *Ṛtusaṃhāra*, *Meghadūta*, *Kumāra-Sambhava*, *Raghuvaṃśa*, *Vikramorvaśīya*, *Mālavikāgnimitra* and *Abhijñāna Śakuntala* are full of beautiful descriptions of nature, the seasonal changes, several animals and plants and insects. Gupta has extracted entomological information of about 18 insects from the great poet's meticulous observations.

The Bṛhatsaṃhitā

Varāhamihira occupies a special position in the history of science in India in view of his wide range of interest and contribution to several fields of knowledge. As an astronomer, astrologer and, above all, an encyclopaedic writer, it is difficult to find his peer. His contributions to astronomy will be discussed in the chapter on astronomy. His encyclopaedic work, the *Bṛhatsaṃhitā*, for which he is sometimes compared with Pliny, is his *magnum opus*. Through this work, Varāhamihira 'shows himself a master of learning of his day in wide fields of knowledge, and thoroughly skilled in language and meter, not at times without a real touch of poetic ability'.[c] A critical scholar, scientist and encyclopaedist like al-Bīrūnī did not fail to notice the merit of the book on which he drew heavily in writing his own *Indica*.

The *Bṛhatsaṃhitā* provides important information on astronomy, geography, medicine, chemistry, perfumery, botany, zoology, agriculture,

[a] Smith (V. A.), p. 24. [b] Renou and Filliozat, p. 207. [c] Keith (3), p. 529.

architecture, psychology, physiology, prosody and several other subjects. In astronomy, planetary motions, asterisms, zodiacal divisions, *tithis*, *karaṇas*, eclipses, etc., are dealt with. Here we meet with the names of several ancient astronomers and astrologers and their works which were probably rendered obsolete by his own masterpiece. Other topics discussed are erotic remedies, including treatment of plant diseases, classification of substances, plant sciences, description of specific characteristics of animals.

With the assistance of Brahmin astronomers of Ujjain, Hunter ascertained the date of Varāhamihira to be *Śaka* 427, that is A.D. 505.[a] Al-Bīrūnī placed him around *c.* A.D. 526.[b] From a study of Āmarāja's commentary on Brahmagupta's *Khaṇḍakhādyaka*, Bhau Daji estimated Varāhamihira's death at A.D. 587.[c]

BUDDHIST LITERARY SOURCES

Unlike the Brāhmaṇic literary sources, those of the Buddhists are relatively of little importance in view of their philosophy of life centring round *nirvāṇa*, primary preoccupation with ethical considerations and a general lack of interest in positive sciences. Exceptions are, however, in the field of medicine, the Buddha himself being acclaimed as the greatest of physicians (*bhaiṣajyaguru*), in certain physical concepts such as atomism and the like. 'Amid the many allusions to human activities in the Canon,' writes Keith, 'we hear of practically nothing scientific, save the pseudo-science of astrology and the practical art of medicine, which unquestionably deeply coloured the outlook and method of the Buddha as the great healer of human evils.'[d] Nevertheless, there are enough indications of their interest in Brahmanical sciences which they adopted without little or no further development and transmitted to other countries along with the spread of Buddhism there. In this way we do come across the *Po-lo-mên* literature in China, dealing with Brahmanical astronomy, mathematics and pharmacy and the *nakṣatra* list in Uigur manuscripts in Central Asia.

The Pali Canon

The Pali Canon represents the teachings of the oldest Buddhist sect called the *Thera* (Sanskrit *sthavira*), meaning the 'ancient', and constitutes, according to the Theravādins (also called the Vibhajyavādins), the most ancient and important source for the understanding of Buddhism. The Canon is called the *Tripiṭaka*, that is 'three baskets'. Its three divisions and subdivisions are:

I. The *Vinayapiṭaka*, dealing with the discipline of the order, including monastic community, daily life of the monks, orders of discipline, etc.

[a] Colebrooke (2), p. xxxiii.
[b] Reinaud, p. 286.
[c] Bhau Daji, p. 407.
[d] Keith (5), p. 89.

It is subdivided into (i) the *Suttavibhaṅga* consisting of *Mahāvibhaṅga* and *Bhikkunivibhaṅga*; (ii) the *Khaṇḍhakās* consisting of *Mahāvagga* and *Cullavagga*; and (iii) the *Parivāra* or *Parivārapāṭha*.

II. The *Suttapiṭaka*, giving short rules, discourses or sermons often in the form of a dialogue. This *piṭaka* comprises five *Nikāyas* (collections), viz. *Dīghanikāya*, *Majjhimanikāya*, *Saṃyuktanikāya*, *Aṅguttaranikāya* and *Khuddakanikāya*.

III. The *Abhidhammapiṭaka*, concerned with the higher subtilities of the religion and providing the psychological basis of the Buddhist ethics.[a] Its subdivisions are: *Dhammasaṅgāni*, *Vibhaṅga*, *Kathāvatthu*, *Puggalapannatti*, *Dhātukathā*, *Yamaka* and *Paṭṭhāna*.

Several passages of the *Tripiṭaka* further indicate the division of the Canon into nine *aṅgas*, e.g. *Sutta* (discourses and sermons in prose), *Geyya* (sermons in prose and verse), *Veyyākaraṇa* (commentaries and explanations), *Gāthā* (stanzas), *Udāna* (pithy sayings), *Itivuttaka* (speeches beginning with 'Thus has been said'), *Jātaka* (stories of former births of the Buddha), *Abbhuta* (miracle stories) and *Vedalla* (questions and answers). These *aṅgas* are indicative of the fact that some of them were certainly present at the time of compilation of the Canon.

Scientific information of some importance is scattered throughout such canonical literature. The *Mahāvagga*, for instance, has a chapter dealing with diseases, their remedies, rules of hygiene, etc. A number of medical legends, including the famous legend of Jīvaka who used to cure diseases by surgery, trepanation and so on, are also found in these canonical works.

According to the tradition, the *Tripiṭakas* were compiled at the first Council of Buddhists held in Rājagaha (modern Rajgir) shortly after the death of the Buddha (*c.* 485 B.C.). Much reliance is not placed on this tradition on the ground that such a voluminous Canon could not have been compiled in so short a time. More reliable is the tradition of a second Buddhist Council at Vesāli about a hundred years after the death of the Buddha, when the monks, faced with a great schism, assembled and rehearsed the *Vinayapiṭaka*. The Ceylonese tradition has it that in the time of Aśoka, about 236 years after the death of the Buddha (that is *c.* 249 B.C.), Tissa Moggaliputta convened a third Council of a thousand monks in Pāṭaliputra to compile the authoritative Canon of the Theravādins. Then there is the vital question of the Pali language of the *Tripiṭaka* as we have it today and the ancient Māgadhī dialect used by the monks of Pāṭaliputra. Winternitz remarks that the Pali *Vinaya* and the *Suttapiṭaka* correspond on the whole to the Māgadhī Canon of the third century B.C.[b] From a consideration of all factors, he concludes that a collection of Buddhist texts called the *Piṭakas*, divided into *Nikāyas*, existed before the second century B.C., probably as early as the time of Aśoka and that this Buddhist

[a] Winternitz, II, p. 9.

[b] Winternitz, II, p. 15.

Canon closely resembles the Pali Canon we now have it.[a] In its present form, the *Tripiṭakas* have probably been in existence from the early centuries of the Christian era.

The non-Canonical Pali Literature

Of the extensive non-Canonical Pali literature, mention may be made of *Milindapañha* (Questions of Milinda) written in the dialogue form which reminds one of the *Upaniṣads*. The work was in all probability composed during the first century A.D. The bulk of the non-Canonical Pali literature consists of commentaries, that is *atthakathās* in which Ceylonese monks excelled. The *Milindapañha* was written somewhere in North-West India.

As to other Indian Pali commentators, we should specially mention Buddhaghoṣa who flourished in the fifth century A.D. Born of a Brahmin family of Magadha and exceedingly well read in the *Vedas*, he embraced Buddhism, spent some time in the Anurādhāpur monastery of Ceylon and wrote several works and commentaries. His works include the *Atthasālinī* (a commentary on the *Dhammasaṅgāni*), the *Viśuddhi-Magga*, a systematic treatise containing a clear exposition of the Buddhistic doctrine, and a number of commentaries on the *Vinayapiṭaka*, *Dīghanikāya*, *Majjhima-nikāya*, *Aṅguttaranikāya* and *Abhidhammapiṭaka*.

The Buddhist Sanskrit Literature

The Pali literature on Buddhism briefly referred to above represents by and large the view of the Theravādins. Other schools and sects, particularly the Mahāyānists, wrote in pure and mixed Sanskrit. This Buddhist Sanskrit literature has come down to us in a rather scattered, sporadic and fragmentary manner as also in translations in Tibetan and Chinese, which are very important for an understanding of this type of literature. A large number of these texts have turned up in Central Asia, Kashmir (ruins of Gilgit), Nepal and Afghanistan (Bāmiyan). A few important ones will be noticed here.

The *Divyāvadāna* (divine exploits) is a non-canonical collection containing at the same time several elements of the *Vinayapiṭaka* of the Mūla-sarvāstivādins. It contains elements characteristic of the Buddhist literature at the beginning of the Christian era and is important for its references to many matters of secular interest, including astronomy.[b] The *Lalitavistāra* (narration of the sport) is concerned with the legend of the Buddha up to the time of his famous sermon at Banaras and is a work intermediate between the Hīnayāna and the Mahāyāna texts. The language is Sanskrit prose sufficiently regular, but sometimes also mixed, more or less resembling another Sanskrit Buddhist text, the *Mahāvastu*. The work was composed

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[a] Winternitz, II, p. 18.

[b] Renou and Filliozat, p. 364.

before the Christian era and was translated into Chinese for the first time in A.D. 308.[a]

The *Laṅkāvatārasūtra*, also called the *Saddharmalaṅkāvatārasūtra*, is one of the important Mahāyāna *sūtras*. The work is important from the point of view of Buddhist physical concepts, at least of the Mahāyāna school, inasmuch as it teaches the *Vijñānavāda*, the doctrine of consciousness and also a modified view of the *śūnyavāda*. It refutes the philosophies of the *Sāṃkhya*, the *Nyāya-Vaiśeṣika* and the sophists. The text was translated into Chinese in A.D. 443 and probably existed between 50 and 100 years before that time.[b] The philosophy of *Vijñānavāda* played an important part during the fourth and sixth century A.D.

The importance of Nāgārjuna in the history of Indian science need hardly be overestimated. Apart from being the founder of the Mādhyamika system of the Mahāyāna, Nāgārjuna, we have it on the authority of Kumārajīva (*c.* A.D. 405), was well versed in astronomy, medicine, production of precious stones and alchemy. Samuel Beal records that he practised the art of converting inferior substances into gold and also discovered an elixir of life. He was the author of the *Mūlamādhyamakakārikā* containing one of the best accounts of the *śūnyavāda* and of several other works. Nāgārjuna's date is debatable. Keith places him around *c.* A.D. 200, Winternitz in the latter half of the second century A.D., and, according to Renou and Filliozat, he lived towards the end of the first century and the first part of the second century A.D.

The *Abhidharmakoṣa* of Vasubandhu who flourished in the fourth century A.D. is an important source book on Buddhist atomism. The Sanskrit original has long since been lost, but the work has survived in the form of a commentary, the *Abhidharmakoṣavyākhyā* by Yaśomitra, and also in Tibetan and Chinese versions. The work was written from the standpoint of the Sarvāstivādins and also dealt with the debates between the Vaibhāṣikas and the Sautrāntikas—Buddhist schools who believed in the atomic constitution of matter. The atomism of these Buddhist schools appears to have been borrowed from the Vaiśeṣikas. Another Buddhist work of uncertain date, but translated into Chinese, is *Abhidharmahṛdaya* in which a much fuller treatment of the atomic theory is met with. The earlier and classical Yogācārins appear to have accepted the theory provisionally, but the later ones led by Dignāga (fifth century A.D.), the famous logician, found no use of it in their system of logic, in which, in consequence, the theory was refuted. Nevertheless Dignāga's *Pramāṇasamuccaya*, *Hetucakranirṇaya*, *Nyāyamukha*, *Nyāyapraveśa* and other works throw important light on the subject. Considerable importance also attaches to the works *Nyāyavindu* and *Sambandhaparīkṣā* by Dharmakīrti (seventh century A.D.), the celebrated successor in the Dignāga school of logic.

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[a] Renou and Filliozat, p. 368.

[b] Winternitz, II, p. 337.

JAINA LITERARY SOURCES

Unlike Buddhism which developed into a world religion, Jainism remained confined within the geographical boundaries of India. Jainism also showed stronger affinities to Brahmanism in many respects. One result of this has been that the Jainas like the Brāhmaṇas, exhibited considerable interest in secular learning and sciences and made notable contributions to philosophy, grammar, lexicography, science of politics, astronomy, mathematics, medicine and other technical matters considered important in their times. This interest is reflected in their oldest canonical literature as well as in the production of a large number of technical literature. The Jainas have a special claim in the development of many of the Indian languages such as Tamil, Telugu and Kannada in the south and Gujarati, Hindi and Mārvarī in the north.[a]

The Canonical Literature

The Jainas call their sacred literature the *Siddhānta* or *Āgama* and believe them to be very ancient. This literature propounds the Jaina doctrine in a discursive manner, and contains rituals, biographies of ancient religious preceptors, the direct teachings (*pravacana*) of Mahāvīra and also profane matters. The number of their canonical texts is stated to be 45 or 50; if some subsidiary elements are taken into account, this number may go up to 84 plus 36 *Nigamas* or *Upaniṣads*. The principal texts are the *Aṅgas*, the *Upāṅgas*, the *Prakīrṇakas*, the *Cheda-sūtras* and the *Mūla-sūtras*.

The *Aṅgas* are twelve in number and generally deal with doctrinal matter, rituals, legends, ethics and so on. These are: the *Ācārаṅga*, the *Sūyagaḍāṅga*, the *Sthānāṅga*, the *Samavāyāṅga*, the *Bhagavatī* or *Vyākhyā-prajñapti*, the *Nāyādhammakahāo*, the *Upāsakadaśa*, the *Antakṛtadaśa*, the *Anuttara-aupapātikadaśa*, the *Praśna-vyākaraṇa*, the *Vipākasūtra* and the *Dṛṣṭivāda*. The *Sthānāṅga* and the *Bhagavatīsūtras*, in particular, contain references to mathematics and astronomy and enumerate the various branches of mathematics.

The *Upāṅgas*, also 12 in number, generally respond to the *Aṅgas*, but their connections with the latter are somewhat loose. The *Upāṅgas* include *Aupapātika*, the *Rājapraśnīya*, the *Jīvājīvābhigama*, the *Prajñāpanā*, the *Sūryaprajñapti*, the *Jambūdvīpa-prajñapti*, the *Candraprajñapti*, the *Nirṇayāvalī*, the *Kalpāvataṃśikā*, the *Puṣpikā*, the *Puṣpaculikā* and the *Vṛṣṇidaśāḥ*. The third *Upāṅga*, the *Jīvājīvābhigama*, as the name implies, puts forward the doctrine of the living and the non-living, gives a detailed classification of living creatures, and discusses the Jaina cosmography further elaborated in the *Jambūdvīpaprajñapti*. The fourth *Upāṅga* has some importance from the point of view of geography and ethnography. The *Sūrya-* and the

[a] Winternitz, II, pp. 427–28; 595.

Candra-prajñapti mean information on the sun and the moon, and are as such astronomical texts which more or less follow some of the precepts and principles found in the *Vedāṅga Jyotiṣa*. There are also important differences in the fact that these texts advocate the theory of two suns, two moons and two series of *nakṣatras* in keeping with their peculiar cosmographical ideas. The sixth *Upāṅga*, the *Jambūdvīpa-prajñapti*, deals with the Jaina views of cosmography comparable in many respects with those of the *Purāṇas*.[a]

The *Prakīrṇakas*, meaning 'dispersed texts', are 10 in number and may be likened to the Vedic *Pariśiṣṭas*. We may specially refer to the *Taṃdula-Veyāliya* which, in the form of a dialogue, discusses among others, matters relating to physiology, anatomy, embryology, measurement of length and time.

The six *Chedasūtras* mainly deal with rituals and have much in common with the Buddhist *Vinayapiṭaka*. One of them is the *Daśaśrutaskandha* containing a *Kalpasūtra* ascribed to Bhadravāhu, who died 170 years after Mahāvīra's nirvāṇa (468 or 467 B.C.).[b]

There are four *Mūlasūtras*, viz. the *Uttarādhyāyana*, the *Āvaśyaka*, the *Daśavaikālika* and the *Piṇḍa-Niryukti*. The first one often compared with the *Suttanipāta* of the Buddhists has great literary merit and contains occasional passages of importance to mathematics.

Finally, we have two individual texts, the *Nāndīsūtra* and the *Anuyoga-dvārasūtra*, sometimes included in the *Prakīrṇakas*. Their importance lies in the fact that they deal not only with religious matters but also with secular subjects such as mathematics, grammar, philosophy, polity, *kāma-sūtra*, drama and the Vedas and refer to standard Brāhmaṇic texts dealing with the *Arthaśāstra*, *Vaiśeṣika* system, *Lokāyata* philosophy and Vātsā-yana's *Kāmasūtra*.[c]

Chronology of the Jaina Canon

The problem of determining the chronology of the different parts of the Canon has been rendered difficult by considerable interpolations and intermixing of fairly recent elements with those of the old. The tradition itself attributes certain portions of the Canon to authors of more or less later dates. At the same time, it is possible to believe that the main core of the teachings must have existed at the time of Vardhamāna Mahāvīra. However, by a process of counting how many times the same themes have been repeated in the various *Aṅgas*, *Upāṅgas*, *Prakīrṇakas* and so on, the numerical series, the citations and diverse interrelationships, Jacobi and Schubring concluded that the most ancient portions of the Canon took their shape during the third and fourth century B.C.[d] From linguistic considerations, the language of the Canon is *ardhamāgadhī* containing

[a] Renou and Filliozat, p. 613.
[b] Winternitz, II, p. 462.
[c] Winternitz, II, p. 473.
[d] Renou and Filliozat, pp. 616–17.

several foreign elements of later date and is clearly different from the dialect which Mahāvīra must have used.

Philosophical, Scientific and Technical Literature

As has already been remarked at the beginning, the Jainas have been credited with a voluminous production of philosophical, scientific and technical literature. One of their earliest philosophers is Kundakunda of the Digambara sect, who flourished during the first century A.D. and wrote the *Pravacanasāra* in aphoristic style to expound the Jaina epistemology and the theories of *tattva* and *astikāya*.

Umāsvāmin, also known as Umāsvāti, was a pupil of Kundakunda and probably lived in the first centuries of the Christian era. His *Tattvārthādhigamasūtra* in which an attempt was made to explain the true nature of things is acknowledged as an authoritative text by both the Digambaras and the Śvetāmbaras. Written in Sanskrit, the work is divided into six sections dealing with true faith, the soul, the universe, the substances and *karman*, and the deliverance. Besides dealing with logic, psychology, cosmography, ontology and ethics, this is the most authoritative text for Jaina atomism, classification of animals and several matters of scientific interest. The work was commented upon by Siddhasena Divākara (seventh century A.D.), Sāmantabhadra (eighth century A.D.), Akalaṅka (ninth century A.D.) and a number of other prominent Jaina teachers. This was a period of great ferment in philosophical disputations in which the Jaina and Buddhist logicians had to defend their systems against the onslaughts of the Mīmāṃsakas and representatives of Brahminical orthodoxy.

Haribhadra was another great Jaina philosopher and encyclopaedic writer (eighth century A.D.) deeply versed in all philosophical systems. In his *Ṣaḍdarśanasamuccaya*, he discussed the philosophical positions of Buddhism, the *Sāmkhya*, the *Nyāya-Vaiśeṣika*, the philosophy of Jaiminī and Cārvāka's materialism. His interest in Dignāga's logic is reflected in his effort to write an unbiased commentary *Nyāyapraveśa*.[a] This work was commented upon by Guṇaratna (fourteenth century A.D.), an able Jaina philosopher and commentator, in his *Tarkarahasyadīpikā*.[b] Hemacandra (twelfth century A.D.) rendered signal service to the development of the science of grammar through his grammatical masterpiece, the *Siddhahemacandra* (*sūtra* and *vṛtti*), a well-arranged work of great clarity.[c] This work, however, was based on *Jainendra Vyākaraṇa* (*c.* A.D. 678) ascribed to Jinendra, but really composed by Devanandin.[d] To Hemacandra is attributed a work on *Nītiśāstra* (*Laghu Arhanniti*) of which the materials were in all probability taken from a prākṛt work no longer extant.

Śāntisūri's (*d.* A.D. 1039) *Jīvavicāra* which means 'investigations on life sciences' is, in fact, a treatise on theology, zoology, botany, anthropology

[a] Winternitz, II, p. 583.
[b] Dasgupta, I, p. 114.
[c] Renou and Filliozat, p. 95.
[d] Keith (3), p. 432.

and mythology. The Jaina canonical and non-canonical texts frequently give the impression, like those of the Buddhists, of their acquaintance with, and interest in, medicine. One Jaina medical text under the title of *Kalyānakāraka* is known, but its date is uncertain.[a] The work is based on Āyurvedic texts with the difference that remedies and prescriptions intended for human beings are extended to the animals in conformity with the Jaina concern for life in general. Regarding astronomy, mathematics and cosmography, the Jainas composed special *Upāṅgas* already referred to and produced a great mathematician in the person of Mahāvīra who lived around A.D. 850.

PERSIAN AND ARABIC SOURCES

The contact between India and Persia and West Asia is very ancient, of which we have evidence from the protohistoric period and particularly from the time of the Achaemenian power in the historic period. In fact, in the time of Darius, the Indus basin formed one of the satrapies of his extensive empire. In these circumstances Indian science and literature found their way into Iran and West Asia at a fairly early date and several typically Indian ideas and concepts appeared in the early literature of the area. This was also reciprocated.

The Persian language, that is *Fārsī*, the language of Fārs, one of the provinces of Persia, is 'the lineal offspring of the language which Cyrus and Darius spoke, and in which the proclamations engraved by their commands on the rocks of Behistun . . . and Naqsh-i-Rustam, and the walls and columns of Persepolis, are drawn up'.[b] Although this ancient language of the Indo-Iranian group has suffered many vicissitudes and its continuity was broken by invasions by the Greeks and by the Arabs, its identity was never lost, being inescapably modified by the culture of the conquerors.

Another important characteristic of the language is the change of the script from the cuneiform to the Pahlavī and later on from Pahlavī to Arabic. Browne has divided the history of the Persian language into three periods,[c] e.g. (1) the Old Persian of the Achaemenian period (550–330 B.C.) written in cuneiform character, of which only inscriptions are available; (2) the Middle Persian of the Sassanian period (A.D. 226–652), written in the Pahlavī script, for which it is generally known as Pahlavī and of which the Zoroastrian theological and liturgical materials constitute the bulk of the literature; and (3) the Modern Persian of the Muhammadan period (from about A.D. 900 to the present day) when the Pahlavī of the Sassanian period adopted the Arabic alphabet with the addition of four letters for phonetic reasons.

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[a] Renou and Filliozat, p. 162.

[b] Browne, I, p. 5.

[c] Browne, I, pp. 7–8.

The effect of Hellenism, as Nöldeke observed, was skin deep. The Pahlavī profoundly influenced the language by producing a large body of theological as well as secular literature covering sciences, particularly during the reign of Nūshīrwān, the Just, the greatest Sassanian king (A.D. 531–579). But Islam and the cultural content represented by it penetrated into the very core of the Persian language. India produced an extensive literature in modern Persian which, growing as it did chiefly under the influence of Hindī and local Prākṛts, was different from the Persian Persian.[a]

From the point of view of history of science in India, the ancient scriptures of the Zoroastrians, the *Zend-Avesta* and their later recensions or recastings in the Sassanian period are of particular interest. According to Geldner, the *Gāthās* of the *Avesta* are the actual utterances of Zoroaster probably dating from 1000 B.C. or even 1400 B.C.[b] Darmesteter has, however, shown that the *Avesta* of the Achaemenian times perished after Alexander's invasion, that it was reconstructed during the first century A.D. in the reign of the Parthian Vologeses I (A.D. 51–78) and this process continued till the Sassanian times when it absorbed many elements of Neo-Platonism and Gnosticism. Moreover, Media was the home of the Zoroastrian doctrine, the old Perso-Medic language was probably its medium, and the earliest literature probably did not go beyond the sixth or seventh century B.C.[c] The *Avesta*, as it existed in the Sassanian period, consisted of 21 *nosks*, of which only one, the *Vendidād*, is now known to us. Portions of at least four others form the text of the *Yasna*. *Vispered*, a book of formulas and doxologies, is supplementary to *Yasna*. The contents of the remaining *nosks* are known to us in summary form from the important Pahlavī work, the *Dinkard*, dating from the ninth century A.D. Some of the scriptural hymns now form the text of the *Yashts*. And finally, we possess the *Khorda Avesta* (the *Little Avesta*) compiled for the laity in the reign of Shāpūr II (A.D. 310–379). The Sassanian *Avesta* contained about 347,000 words of which only some 83,000 or one-fourth have survived.[d]

Filliozat has shown many parallelisms between the medical, physiological and pathological doctrines of the *Āyurveda* and those of the *Avesta* in its surviving texts represented by the *Vendidād*, the *Yasna*, the *Yashts* and others, although differences are also many.[e] In astronomy, similar parallelism and differences are known. That such exchanges of ideas took place are attested by the development of Jundīshāpūr, under Nūshīrwān, as a leading centre of Persian medicine, in which Indian *Āyurvedic* system was syncretized with the Greek system propagated there by the Nestorian Christians. Burzūya, physician to Nūshīrwān, was actually sent to India to bring back Indian works on medicine, the *Pañcatantra* (the *Book of Fables*) and the game of chess. The medical works and the *Book of Fables*

[a] Ghani, pt. 1, pp. ix–x.

[b] Geldner, 'Zoroaster' in the *Encyclopaedia Britannica*, 9th ed., 1888. He also produced a German translation of the *Avesta*.

[c] Browne, I, p. 96; *see also* Darmesteter, *Études Iraniennes*.

[d] Browne, I, p. 98.

[e] Filliozat (2), pp. 29–66 (French version).

were translated from Sanskrit into Pahlavī. The Jundīshāpūr school of medicine continued its active existence and, after the Arab conquest of Persia, exerted a great influence on the development of Arabian medicine.[a]

During the Caliphate, when vigorous centres of learning sprang up in the newly founded cities of Baghdad, Basra and Kūfa, and streams of learning began to pour in from Persia, India and the Byzantine Empire, the Sassano-Persian language still played the dominant role, particularly as a court language and as the language of belles-lettres and poetry. 'The Persians', writes Sarton, 'introduced into the Caliphate a greater love of beauty, urbanity, intellectual curiosity, and much fondness for discussion. These conditions were favourable for the progress of science . . .'[b] And so it was no accident that the early architects of science through the Arabic medium were either Persians or Jews or Christians. Thus Ibrāhīm al-Fazārī, Ya'qūb ibn Ṭāriq, al-Naubakht, Ibn al-Muqaffa were Persians, Māshāllāh was an Egyptian Jew, and the Bakhtyashū' family who did much to develop medicine were Nestorian Christians. Interest in the development of the Persian language never languished even after Arabic became the international language of science. In the tenth century A.D., Abū Manṣūr Muwaffaq ibn 'Alī al-Harawī of Herat, a Persian pharmacologist, wrote his *Kitāb'l-Abniya 'an Haqā'iq'l-Adwiya* (*Book of the Foundations of the True Properties of the Remedies*). Believed to be the oldest prose work in modern Persian,[c] the book utilized materials from Greek, Syriac and Indian medical sources. In the second half of the eleventh century A.D., al-Ḥasan ibn al-Ṣabbāḥ, Omar Khayyām, mathematician and poet, Nāṣir-i-Khusraw, poet and geographer, Zarrīn Dast, ophthalmologist, and Asadī, lexicographer, all wrote in Persian. As a language of literature and poetry, if not of the sciences, Persian reached its highest watermark in Firdawsī.

The *Qur'ān* introduced a new and vigorous language, Arabic, which was destined to become the international language of knowledge and culture and of sciences, in particular, for several centuries. The work was edited twice by Zaid ibn Thābit (*d.* A.D. 673–74), and his final edition has remained the standard version ever since.[d] Arabic, like Voltaire's French, is a dry, precise and practical language eminently suitable for the exact sciences. Its great advantage lies in its facility, like Sanskrit, to lend itself to the easy coining of technical terms.

It was again left to the Persian élite, as remarked before, to appreciate the power and merit of the new language. The first Arabic grammar, for example, was composed not surprisingly by Abū-l-Aswad (*d. c.* A.D. 688), a Persian of Basra. Basra and the rival city of Kūfa in Iraq also witnessed the rise of early grammatical schools for the simple reason that the mixed population of these cities, after the Arab conquest, needed this key and instrument for the mastery of Arabic much more than the Bedouins who

[a] Sarton (1), I, p. 435.
[b] Sarton (1), I, p. 524.
[c] Leclerc, I, pp. 361 ff.; Browne, I, pp. 11, 478.
[d] Sarton (1), I, p. 465.

spoke it as their mother tongue. In this case the parallel with the Greek grammar is very close, for the latter also arose not among the Athenians but among the mixed Alexandrians for whom it was a practical necessity.[a]

When the grammatical and philological foundation of the Arabic language was thus being laid, simultaneous efforts on a much more extensive scale were made to enrich the literature by absorbing the materials from foreign sources, notably Persian, Indian and Greek. Ibn al-Muqaffa translated Pahlavī works on logic and medicine and also the *Kalīla-wa-Dimna*, originally transmitted to Persia from India. An Arabic translation from a Persian version of the *Caraka Saṃhitā* was also probably made during this early phase, as we have it from the *Fihrist*.[b] Another early Pahlavī book, the *Zik-i Shatro-ayār*, an astronomical work based on Indian elements, was translated into Arabic by al-Tamīmī under the Arabic title *Zij-ashshahrīyār*.

During the reign of the second Abbāsid Caliph al-Mansūr (753–774), Sanskrit scientific works were directly available for either translations or use in composing scientific texts in Arabic. In astronomy and mathematics, as we shall see later on in chapters on these subjects, Ibrāhīm al-Fazārī (*d.* 796 or A.D. 806), Ya'qūb ibn Ṭāriq, al-Khwārizmī (*d. c.* A.D. 850), al-Kindī (*d. c.* A.D. 873), Habash al-Hāṣib (*d. c.* A.D. 864 or 874) and a few others translated Sanskrit works into Arabic and/or wrote independent works explaining the Indian system and methods of calculations. In this effort, Indian astronomers and physicians engaged in Baghdad played no small part either as interpreters of Sanskrit texts or as translators into Arabic itself, which they must have mastered for this task.

Many of these early Arabic translations of, or works on, Indian scientific texts were lost, and a few have been preserved in Latin translations. But of works no longer extant, our main source of information is the *Fihrist* or 'Index' of Abu'l-Faraj Muhammad *b.* Ishāq al-Warraq of Baghdad, better known as ibn Abi Ya'qūb an-Nadim, composed in A.D. 988. One of the most valuable and remarkable encyclopaedic works in Arabic (edited by Flügel), the *Fihrist* records ancient works and views on philosophy and science in its seventh discourse, in three sections, as follows: (1) account of materialist philosophers and logicians; (2) account of mathematicians, arithmeticians, geometricians, astronomers, scientific instruments makers, mechanics and engineers, musicians and accountants; and (3) account of medicine, its origin, names of physicians and medical texts, ancient and modern. The ninth discourse deals, among others, with Indian sects, and the tenth discourse is devoted to alchemy.[c]

As far as Indic studies among the Arabic and Persian scholars are concerned, nobody surpassed Abū Raiḥān Muhammad ibn Aḥmad al-Bīrūnī (973–1048), a Persian by birth and a Shi'ite. During the period between A.D. 1017 and 1030 when he was travelling, as a political hostage,

[a] Brockelmann, I, pp. 42, 96–98; Sarton (1), I, pp. 490, 502, 524.
[b] Sachau, I, p. xxxi.
[c] Browne, I, pp. 386–87.

with Maḥmūd of Ghazna in the course of the latter's Indian campaigns, al-Bīrūnī spent a good part of it in different parts of north-western India, studied Sanskrit, went over the original Sanskrit manuscripts to check up earlier Arabic writings on India and approached the whole subject with a critical mind and a scientific detachment rare in those days. His well-known works are the *Kitāb al-āthār al-bāqiya 'ani-l-qurūn al-khāliya* (Chronology of Ancient Nations), discussing the calendars and eras of various peoples, including the Indians, the *Ta'rīkh al-Hind* (Account of India), dealing, among others, with Indian sciences, particularly astronomy in great detail, the *al-Qānūn al-Mas'ūdī* (an astronomical encyclopaedia) and the *al-Tafhīm li-awā'il Sinā'at al-tanjīm* (a summary of mathematics, astronomy and astrology). Sachau tells us that he composed about 20 books on India, both translations and original works, and also a number of legends and tales based on folklores of ancient Persia and India.[a] Besides his professional interest in Indian astronomy, mathematics and geography, already roused by the works of his predecessors like al-Khwārizmī, al-Kindī and Abū-Mā'shār of Balkh, he developed a great deal of interest and fondness for Indian philosophical literature, particularly the *Sāṃkhya*, the *Yoga* and the *Bhāgavatgītā*. He was possibly the first foreign scholar to have seriously studied the *Purāṇas*, specially the *Viṣṇudharma*, the *Viṣṇu*, the *Matsya*, the *Vāyu* and the *Āditya*, as he incorporated several extracts from them in his *Ta'rīkh al-Hind*. It is needless to emphasize the importance of al-Bīrūnī's works as a source of inestimable value for the study of the history of science in India.

It has already been mentioned that India produced an extensive literature in Persian. In Iran, the language was enriched by the assimilation of Turkish, Arabic, French and Russian words, phrases and idioms; in India, a similar process went on in which the vitality of the language once again manifested itself in the absorption of many Hindi and Prākṛt words and idioms. The Turks who established their powers in India and introduced Persian in Hindustan usually spoke Turki and did not have Persian as their native tongue, although many of them could speak the language fluently. The Princes of the House of Timur and Bābur, the founder of the Mughal Empire, had a great love for Persian and adopted it as their own literary tongue.[b] Bābur, of course, wrote his autobiography in Turki, but he was sufficiently accomplished in Persian to be able to compose poetry in it. Even in the course of his brief acquaintance of India, he came under the influence of Indian languages and used hundreds of Hindī and Urdu words in his Memoirs. Ibn Batūta who wrote in chaste Arabic could not avoid the use of Indian words in his travel account.

Of the Persian literature produced in India, the scientific and technical one represented no small part, as the bibliographical studies undertaken by the Medieval Period Unit of the History of Science study group of the National Institute of Sciences of India (now renamed Indian National

[a] Sachau, I, p. xxvii.

[b] Ghani, pt. i, p. 46.

Science Academy) indicate. These vast materials are yet to be studied and analyzed, and when this is done we expect to be in a better position to assess the contribution of Medieval India to the development of science and technology as far as concerns Persian and Arabic. The same is also true of other medieval *apabhraṃśa* languages, the scientific contents of which have so far received scant attention.

Nevertheless, of the editions, translations and studies of some of the works already made, Abū'l-Fazl's (1551–1602) *Ā'in-i Akbarī* deserves special consideration. This Imperial Gazetteer of Akbar's time is full of interest from the point of view of science and technology. Here we find not only an account of Indian and Arabic astronomy, but also a long list of lattitudes and longitudes of places in India, compiled from the works of al-Bīrūnī, the Marāgha school of astronomers and other sources. The *Ā'in* is an important source book for botany and agriculture in Medieval India. In zoology, it has long chapters on elephants, horses, camels and other animals. In metallurgy, particularly centring round coinage, we have valuable information regarding the determination of the purity of gold and silver in coins, processes of refining and casting these metals, preparation of alloys like brass and their use in making various objects. In pyrotechnics and in the technology involved in the manufacture of guns and canons, their upkeep, cleaning of gun-barrels, etc., the *Ā'in* records details of inestimable value and mentions, among a number of scientists, Fathullah Shirazi, a versatile genius.[a]

The Memoirs of Jahangir, the *Tuzuk-i-Jahangīrī*, is another important source for medieval zoology and horticulture, although matters of scientific interest relating to diseases like plague, hydrophoebia due to mad dog-bite, eclipse, comet and meteorites are occasionally mentioned.[b]

SPECIAL SCIENCES

Astronomy and Mathematics

We have already referred to the *Vedāṅga Jyotiṣa* in the *Ṛk* and the *Yajus* recensions and to the Jaina astronomical texts, the *Sūryaprajñapti* and the *Candraprajñapti*. During the first few centuries when astronomy in India was undergoing important and radical changes and assuming the character of an exact science through the use of the mathematical apparatus, a number of *siddhāntas* appeared, of which only a few survived because of their better accuracy in the reckoning of time. In Varāhamihira's *Pañca-siddhāntikā* (*c*. A.D. 505), we have the summary of the principal astronomical elements of five *siddhāntas*, e.g. the *Paitāmaha*, the *Vaśiṣṭha*, the *Pauliśa*, the *Romaka* and the *Saura* (also called the *Sūrya*). The last named *siddhānta* described by Varāhamihira as the most accurate had a career of

[a] Alvi and Rahman (1), p. 1. [b] Alvi and Rahman (2), pp. 129, 132, 136, 137 and 139.

continuous development in the course of which it absorbed new concepts and methods from later astronomers like Āryabhaṭa I, Bhāskara I, Brahmagupta, Mañjulācārya and others.

Because of the mathematization, the early *siddhāntas* are important source materials for both astronomy and mathematics. In fact, most of them have separate chapters or sections giving rules for solutions of various types of problems in arithmetic, algebra, geometry and trigonometry in order that astronomical rules and formulae can be understood without difficulty. In this class we have Āryabhaṭa I's (*b*. A.D. 476) the *Āryabhaṭīya*; Bhāskara I's (*c*. A.D. 600) the *Mahābhāskarīya*, the *Laghubhāskarīya* and a commentary on the *Āryabhaṭīya*; Brahmagupta's (*c*. A.D. 598) the *Brāhmasphuṭa-siddhānta* and the *Khaṇḍakhādyaka*; Vaṭeśvara's (*b*. A.D. 880) the *Vaṭeśvarasiddhānta*; Mañjulācārya's (*c*. A.D. 932) the *Laghumānasa*; Āryabhaṭa II's (*c*. A.D. 950) the *Mahāsiddhānta*; Śrīpati's (*c*. A.D. 999) the *Dhīkoṭi* and the *Siddhāntatilaka*; Śatānanda's (*c*. eleventh century A.D.) the *Bhāsvatī*; and Bhāskara II's (*b*. A.D. 1114) the *Siddhānta-śiromaṇi* divided into four parts, viz. the *Līlāvatī* (on arithmetic), the *Bījagaṇita* (on algebra), the *Gaṇitādhyāya* and the *Golādhyāya* (the last two on astronomy).

As to texts dealing exclusively with mathematics in this period, mention may be made of the Bakhshālī Manuscript (*c*. third or fourth century A.D.); Mahāvīrācārya's (*c*. A.D. 850) the *Gaṇitasāra-saṃgraha*, representing a final synthesis of Jaina mathematics and drawing freely upon previous or contemporaneous Brahminical texts; Śrīdharācārya's (*c*. A.D. 991) the *Pāṭīgaṇita* and the *Triśatikā*; Śrīpati's the *Gaṇitatilaka*; and Nārāyaṇa's (*c*. A.D. 1350) the *Gaṇita-kaumudī* and the *Bījagaṇitāvataṃśa*.

There are several commentaries on the above-mentioned astronomical and mathematical works which appeared mostly during the medieval period, say, from after the time of Bhāskara II (there are notable exceptions such as works of Bhāskara I, Pṛthūdakasvāmī (*c*. A.D. 864), Govindasvāmī (*c*. A.D. 800–850) and a few others). The contributions made by these commentators will be discussed in chapters on astronomy and mathematics. Some of them like Parameśvara (*c*. end of fourteenth and early fifteenth century A.D.), Nīlakaṇṭha Somasutvan (1465–1545), and some members of Divākara and Vallāla families showed originality and wrote independent works.

During the medieval period, a large number of important mathematical and astronomical texts in Arabic and Persian originating in the Arab world of scholarship were in circulation among the intellectual groups in India. Thus we have Euclid's Arabic version, the *Sharḥ Uqlidas*: Thābit b. Qurra's (*d*. A.D. 901) the *Kitāb Arshīmīdas fi'd-Dawā'iri'l-Mutamāssah* and the *Kitāb Arshīmīdas fī Uṣuli'l Handasah*; Naṣr b. 'Abdullah's (*c*. tenth century A.D.) the *Ar-Risālah fī Auna'l-Ashkāla . . . mina'd-Dā'irah*; al-Karkhī's (*d*. *c*. A.D. 1019) the *Kitāb al-Fakhrī fi'l Ḥisāb Jabr-i-Wa'l Muqābilah*; al-Bīrūnī's (973–1048) the *al-Kitāb fī Istikharājil-Autār fi'd-Dā'irah bi-Khawāssi'l-Khaṭṭi'l Munḥani'l-Wāqi'fihā*, the *al-Maqālah fī Rāshikāli'l Hind*, and the

Riyāḍatu'l Fikr Wa'l 'Aql; al-Khayyāmī's (*c.* A.D. 1110) *Maqālah fī-l-Jabr-i*; Ahmad b. Thābit's (*c.* twelfth century A.D.) the *Ghunyatu'l-Hussāb fī 'Ilmi'l-Ḥisāb* and the *'Umdatu'r-Rā'id*; al-Ṭūsī's (1201–74) the *Taḥrīr-u-Uqlidas*, the *Maqālah-i-Arshīmīdas fī Taksīri'd-Dā'irah*, the *Kitābu'l-Kurah Wal-Usṭuwānah* and the *Ar-Risālatul-Qiṭa'fī 'Ilmī'l-Handasah*; Zainu'l-Ābidīn's (*c.* A.D. 1460) the *'Uyūn'l Ḥisāb*, and Bahā'u-ddīn al-Āmulī's (1547–1627) the *Khulāṣatu'l-Ḥisāb*, to mention a few.

We also know of a number of able commentators who produced explanatory treatises, translations, etc., on mathematics. Some of them are Golkonda's Abū Isḥāq b. 'Abdu'llāh (*c.* 1555), Abū'l-Faiz Faizī (*c.* A.D. 1587), 'Aṭau'llāh Rashīdī (*c.* 1634), Mīr M. Hāshim b. Qāsim al-Ḥusainī, Medhnī Mal (*c.* 1663), Ismatu'llāh as-Sahāranpūrī (*c.* 1684) and Luṭfu'llāh Muhandis (*c.* seventeenth century A.D.), whose works will be noticed in the section on mathematics.

No less important are the efforts of men like Mahendra Sūrī (*c.* fourteenth century), Kamalākara (*c.* A.D. 1616), Nīlakaṇṭha Jyotirvid, Samrāṭ Jagannātha (*b.* A.D. 1652), Nayanaśukhopādhyāya (*c.* A.D. 1730) and others, some of whom translated Arabic and Persian texts on astronomy and mathematics and some incorporated new principles and methods found in these texts in their Sanskrit works based largely on traditional Brāhmaṇic methods. In an earlier age al-Adami, al-Fazārī, Ya'qūb ibn Ṭāriq, al-Khwārizmī and several others working outside India and al-Bīrūnī spending some time in India rendered this signal service of syncretizing India's contributions with the new rising astronomical-mathematical learning among the Arab intelligentsia.

The Āyurvedic System of Medicine

The history of the development of the *Āyurveda* literature is discussed in the chapter on Medicine. The most ancient medical treatises that have come down to us are the *Bhela Saṃhitā*, the *Caraka Saṃhitā* and the *Suśruta Saṃhitā*. The first two *saṃhitās* follow the teachings of the school of Ātreya, a famous physician of antiquity, mentioned in several Buddhist texts. According to another tradition, the mythical Bharadvāja was the teacher of Ātreya Punarvasu to whose school belonged Bhela and Agniveśa. It is not possible to say whether this Ātreya Punarvasu and Ātreya of the Buddhist tradition were the same person.[a] The possibility of several Ātreyas is not, however, excluded. The extant *Bhela* or *Bheḍa Saṃhitā* is in a mutilated form; a fragment of the same text has been discovered in Central Asia.[b] The original *Bhela Saṃhitā* might be a work of the *Brāhmaṇa* period. Agniveśa of the Ātreya school probably compiled a medical treatise which formed the basis of the *Caraka Saṃhitā*, as is evident from the colophones of the latter, running as follows: *agniveśakṛte tantre carakapratisaṃskṛte* (in the *tantra* by Agniveśa, as redacted by Caraka). The

[a] Filliozat (2), p. 9.

[b] Renou and Filliozat, p. 151.

Caraka Saṃhitā was again revised by Dṛḍhabala, a Kashmirian physician, who flourished either in the eighth or ninth century A.D. Caraka's date has been much discussed, and there is general agreement in placing him in *c.* A.D. 100.

Suśruta belonged to another parallel school, that of Divodāsa-Dhanvantari, one Bharadvājadhanvantari being mentioned in the *Sāṅkhāyana-gṛhyasūtra.*[a] It is doubtful if Suśruta is a historical personage as the *Saṃhitā* going by his name appears to be the work of a school and to have undergone several revisions even before the emergence of the extant text in the redaction of Nāgārjuna. Is this Nāgārjuna, the redactor of the *Suśruta Saṃhitā*, the same as the founder of the Mādhyamika system of the Mahāyāna Buddhism or the author of the *Yogośataka* (*c.* fourth century A.D.) or the alchemist bearing the same name (ninth century A.D.), mentioned by al-Bīrūnī? The identification of several such Nāgārjunas is still an open question. The commonly accepted date of this finally redacted text is between third and fourth century A.D., and the original *Suśruta Saṃhitā* probably existed several centuries earlier, say, during the last few centuries before the Christian era.

Archaeological explorations carried out in Central Asia yielded from Kashgar the important medical text, the Bower Manuscript, also called the *Nāvanītaka*. Written in a kind of barbarous Sanskrit heavily mixed with Prakṛt words, the text follows the teachings and prescriptions of ancient medical *saṃhitās* and cites as its authorities Ātreya, Kṣarapāṇi, Jatukarṇa, Parāśara, Hārita, Bhela and Suśruta. On palaeographic ground, Hoernlé (4) dated the Bower MS. to between A.D. 350 and 375. Another manuscript (a few pages only) discovered from the region of Kūcha in Central Asia is the *Yogośataka* belonging to the seventh century A.D. (possibly a copy of the similar text attributed to Nāgārjuna, dated three centuries earlier) and at one time popular in Tibet, Nepal and some parts of India. This *Yoga-śataka*, in the opinion of Filliozat, responds closely to the eight-limbed medical treatise mentioned by I-tsing.[b]

Other important medical works of later dates include the elder Bāgbhaṭa's *Aṣṭāṅgasaṃgraha* and the younger Bāgbhaṭa's *Aṣṭāṅgahṛdaya-saṃgraha* (between seventh and eighth century A.D.), Mādḥavakara's *Rugviniścaya* or *Nidāna* (eighth or ninth century A.D.), Vṛnda's *Siddhayoga* (eighth or ninth century A.D.), Cakrapāṇidatta's *Cakrasaṃgraha* or *Cikitsā-sārasaṃgraha* (*c.* A.D. 1050), Śārṅgadhara's *Saṃhitā* (thirteenth century A.D.), Vaṅgasena's *Cikitsāsaṃgraha* (eleventh or twelfth century A.D.), Bhāvamiśra's *Bhāvaprakāśa* (sixteenth century A.D.) and numerous other monographs, *nighaṇṭus* (medical lexicons) and commentaries.

The Unani System of Medicine

The principal sources on which the Unani system of medicine, as practised and developed in India, depended are the *Firdausul-Hikmat* by

[a] Filliozat (2), p. 5; Renou and Filliozat, p. 143.

[b] Renou and Filliozat, p. 157.

'Ali b. Rabban (A.D. 850), the *Qānūn* of ibn Sīnā (A.D. 980–1036) and several works by other leading Arab physicians. Although, to start with, the system was based primarily on the Greek system, it was later on enriched by the experiences of the Arab physicians as also by the Āyurvedic system to which they had access. From about the thirteenth or fourteenth century A.D., practitioners of the Unani system in India produced a number of important medical works. Thus, in A.D. 1320, Hakim Diya Muhammad wrote his *Majmuai-Diyaiyya*. This work refers to an earlier work, the *Majmuai-Shamaiyya*, a Persian translation of an Āyurvedic book, by Shamsuddin Mustaufi. Other works include the *Tibbe Firozshahi* dictated by Firoz Shah Tughlaq himself; the *Macdanush-Shifai-Sikandari* compiled, under the orders of Mian Bhowa, by a number of Hakims and Āyurvedic physicians; the *Tibbi-Shifaul-Khani* and the *Tibbe-Shihabi* by Hakim Shahabuddin (fifteenth century A.D.); the *Tibbe-Shifai-Mahmudi* (fourteenth century) during the reign of Mahmud Shah, the Bahamanid ruler of the Deccan; a Persian translation of Vāgbhaṭa's work by Hakim 'Ali Muhammad (fifteenth-sixteenth century A.D.) and the *Dasturil-Atbba*, also called the *Ikhtiyarati-Qasim*, by Hakim Muhammad Qasim Hindu Shah (A.D. 1590).

Under the Mughal rulers, the system received further encouragement. A large number of Hakims and Āyurvedic physicians were engaged in producing commentaries, translations, etc., of original Arabic works and also in translating and adapting Āyurvedic works. Thus, we have the *Tibbi-Aurangzebi*; the *Muslajati-Darashikohi*; the *Talifi-Sharifi* and the *Tuhfa-Alamshahi* by Hakim Sharif Khan (A.D. 1725–1806), the *Iksiri-Azam* by Hakim Muhammad Azan, and the *Jami ush-Shifaiya* by Hakim Afdal Ali of Faydabad (A.D. 1878).

Veterinary Science

Diseases of animals and their treatment received no less attention in ancient and medieval India. Cows, horses and elephants received special consideration in view of their importance in Indian economy, and it is not surprising that a sizeable literature has come down to us, dealing with the diseases of these animals. The *Gavāyurveda* attributed to Gotama is concerned with the diseases of bovine animals and their treatment. On the equine *Āyurveda*, the most important work is the *Śālihotra Saṃhitā* of uncertain date, although great antiquity is claimed for its legendary author Śālihotra. It was redacted by Kalhana (twelfth century A.D.) under the title *Śālihotrasārasamuccaya*. Other important books on the subject are the *Aśvavaidyaka* of Jayadatta Sūrī and the *Aśvaśāstra* by Nakula, both of uncertain dates.[a] The medical encyclopaedia, the *Rājamārtaṇḍa*, by Bhojarāja, which contains several references to veterinary sciences, mentions the *Sārasaṃgraha*, another work by Nakula, the *Hayalīlāvatī* by Jayadeva and the *Vājicikitsā Saṃgraha* by Jayadatta. On elephants, the classical

[a] Renou and Filliozat, p. 165.

work is the *Pālakāpya Saṃhitā*, also known as the *Hastyāyurveda*, attributed to Pālakāpya, but compiled most probably by one of his disciples in medieval times.[a]

Iatrochemical and Alchemical Texts

It is difficult to say since when metallic preparations, inorganic salts and alloys, particularly the preparations of mercury, began to find use in the treatment of diseases in India. The use of mercurial compounds and a number of chemical processes such as calcination, making of alkalies, etc., were known to Suśruta and Caraka. In the course of time such iatrochemical practices and applications of inorganic remedies developed into a new branch of knowledge called the *rasaśāstra* or the *rasacikitsā* school of medicine. Accordingly, the contents of this class of literature are discussed in the chapter on medicine from the iatrochemical point of view and in the chapter on chemical practices and alchemy, for their obvious contribution to the growth of alchemy.

The specific literature on the subject began to develop from the seventh or eighth century A.D., but the most active period of its growth is noticed between the tenth and fourteenth century A.D. Here we mention only a few important texts and more will be noticed in chapters referred to. These are: the *Rasaratnākara* and the *Ārogyomañjari* of Siddha Nāgārjuna (seventh century A.D.), the *Siddhayoga* of Vṛnda, *Cakrasaṃgraha* of Cakrapāṇidatta, *Rasahṛdaya* of Govinda Bhāgavat (eleventh century A.D.), *Rasārṇava* by an unknown author (twelfth century A.D.), *Rasendracūḍāmaṇi* of Somadeva (twelfth-thirteenth century A.D.), *Rasaratnasamuccaya* by Vāgbhaṭa (twelfth century A.D.), *Rasaprakāśasudhākara* by Yaśodhara (*c.* twelfth–thirteenth century A.D.), and *Rasendracintāmaṇi* by Rāmacandra (twelfth century A.D.). Another *Rasaratnākara*, attributed to Siddha Nityanātha, is likely to be a fourteenth-century work; some of the works belonging to the same century include *Rasarājalakṣmī* by Viṣṇudeva, physician to the king Bukka of Vijayanagar, *Rasanakṣatramālikā* by Mathanasiṃha, the *Rasasāra* by Govindācārya, *Rasendra-sārasaṃgraha* by Gopālakṛṣṇa and *Dhāturatnamālā* by Devadatta.[b] Although these *rasa* texts are not free from Tantrik elements, these are not regarded as typical Tantrik works either. On the other hand, typically Tantrik texts sometimes deal with serious alchemical precepts, of which the *Mātṛkābhedatantra* and the *Rasārṇavakalpa* of the *Rudrayāmalatantra*, in Sanskrit, are some examples. There is an abundant literature on the subject in languages other than Sanskrit, particularly in Tamil, in which the Siddha system under the name *sittar* flourished.

Gunpowder and Pyrotechnics

Apart from references to the making of gunpowder in general texts of the nature of *Śukranīti*, there exist a number of manuals in Sanskrit,

[a] Renou and Filliozat, p. 166.

[b] Renou and Filliozat, p. 169.

Marathi, Tamil, Malayalam and Persian, dealing with gunpowder and pyrotechnics. Some of them are the *Kautukacintāmaṇi* by Pratāparudradeva (c. A.D. 1497–1539), *Ākāśabhairavakalpa* (c. fifteenth century A.D.) in Sanskrit; the *Rukminīsayamvara* by Ekanātha (c. sixteenth century A.D.) in Marathi; the *Bāṇaśāstra* and the *Bogarsutiram* in Tamil; the *Vetikkampavidhi* by Nīlakaṇṭha in Malayalam; and a Persian work on pyrotechnics by Zain-ul-Abidin (A.D. 1421–72).

Botany, Agriculture and Zoology

As we have already seen, archaeological sources provide a good deal of information from which some kind of reconstruction is possible as to the state of knowledge regarding these sciences during the pre- and protohistoric period. In the chapters concerned, such an attempt has been made. Then we have general literary sources such as the *Saṃhitās*, the *Brāhmaṇas*, the *Upaniṣads*, the *Sūtras*, the *Arthaśāstras* and related works, the Epics, the *Purāṇas*, lexicographic, encyclopaedic and medical works, which contain bulk of the information relating to these subjects in a scattered form. Presentation of a coherent picture out of such scattered mass of materials is indeed a formidable task.

We fortunately possess special treatises dealing with botany and agriculture. The *Agnipurāṇa*, the *Arthaśāstra* and the *Bṛhatsaṃhitā*, by including a special chapter on *Vṛkṣāyurveda*, the Sanskrit name for plant science, clearly indicate the existence of a separate treatise on botany. Such *Vṛkṣāyurveda* texts written by Parāśara and Surapāla are now available in manuscript form in a number of libraries in India.[a] A copy of a manuscript by Parāśara has been noticed by N. N. Sircar; the work was possibly written between the first century B.C. and first century A.D. Surapāla's *Vṛkṣāyurveda* possibly belonged to c. eleventh century A.D. The *Kṛṣi-Parāśara*, also known as *Kṛṣi-samgraha*, *Kṛṣi-paddhati* and *Kṛṣitantra*, an important work on agriculture, was written between A.D. 950 and 1100.[b]

For information concerning botany, agriculture and zoology in the Medieval Period, we have likewise to depend largely on historical chronicles available in the form of memoirs, and administrative and revenue literature, of which, as we have already remarked, the *Ā'in* is our most valuable source.

Sciences in the Modern Period

In the present book it has not been our intention to deal with the history of modern sciences in India in the same pattern followed for the previous periods. Significantly, therefore, our last chapter has been styled as the impact of Western science on India up to the end of the nineteenth century. The materials of the Modern Period are very vast indeed. We have simply to recall the enormous amount of records such as the Minutes

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[a] *See* Bibliography given in the *Agriculture in Ancient India.*

[b] Majumdar and Banerji, *Kṛṣiparāśara*, p. viii.

of the Bengal Council, Military, Public, Political and Revenue Consultations of Bengal, Bombay and Madras, Court Despatches to Bengal, Bombay and Madras, Records of the Medical Board, the various Surveys and scientific establishments and the bewildering amount of scientific papers, memoirs, books and monographs produced during the period. The study and analyses of these materials for reconstructing the history of science of the Modern Period involve a lifetime's work by several scholars. Crawford's *History of Medical Service in India*, 1600–1913, in two volumes (1914), Phillimore's *Historical Records of the Survey of India*, in four volumes (1945–58), and Burkill's *Chapters in the History of Botany in India* (1965) are a few examples of what is involved in this kind of study. Even then these works were concerned with specially selected areas. The magnitude of an integrated study of the history of science of the period with a balanced emphasis on the role of historical, social, economic and political forces in the development of scientific institutions and of sciences themselves can be easily understood. Unlike the previous periods, here the advantage is that the materials are readily available without presenting formidable linguistic difficulties inherent in oriental studies pertaining to the Ancient and the Medieval and the disadvantage is that such materials are too vast.

2 ASTRONOMY

S. N. Sen

MAN's interest in the heavens is perhaps as old as the beginning of his career as *homo sapiens* on this planet. This is doubtless a consequence of his erect posture which enables him to look and wonder at the sky and the various striking phenomena occurring there day by day and night by night. The sun, the moon, the vault of the sky with numerous sparkling stars, bright and dim, must have appealed to him at the dawn of his capacity to wonder at, and indulge in certain amount of speculation about them. Moreover, he was impressed by the regularity of appearance and disappearance of these objects. The sequence of day and night, the obvious connection of the sun with such alteration of light and darkness, the regular revelation of the splendour of the nightly sky, the periodic waxing and waning of the moon and the unchanging character of the stellar vault must have fired the imagination of the primitive man.

It did not perhaps take the primitive man a long time to discover some kind of relationship between the cycle of his activities and the regularity of the heavenly phenomena. Thus were differentiated his day-time activities from the nocturnal. He noticed that his hunting seasons and, more particularly, his sowing times, when he settled down as a primitive agriculturist, depended on climatic changes or the seasons. He vaguely felt that these periodic changes were somehow connected with the most conspicuous of all heavenly bodies, the sun. In lower Egypt the periodical overflowing of the Nile was noticed to have some connection with the heliacal rising of Sirius.

Such cycle of events in the life processes on the one hand and the regularity in the heavenly phenomena on the other inevitably led to a time sense. At the same time these suggested methods of marking and measuring time to an intelligent priestly class wherever human civilizations sprang up and had their normal course of development. This priestly class, as is well known, had a dominant role to play in human societies, with powers to regulate religious and, not infrequently, the secular life of their fellow members. Everywhere they evolved an elaborate and complicated system of rituals and sacrifices to be performed with perfect regularity in time. This naturally imposed on them the task of measuring and dividing time or,

in other words, of evolving a suitable calendar and consequently of studying astronomical phenomena. This is true as much of the temple priests of Thebes, Nineveh, Sumer and Akkad as of the Brāhmaṇas of Vedic India.

The whole corpus of the Vedic literature represents the intellectual activity of a sacerdotal caste which, by turning to account the religious instincts of a gifted and devout race, transformed a primitive worship of the powers of nature into a highly artificial system of sacrificial ceremonies. In prescribing rules for the observance of such ceremonies, the priestly leaders never tired of emphasizing the importance of carrying them out in proper times. This clearly envisaged a dependable calendar. Thus, the building of the different types of fire altars and consecration (*agnyādhāna*), or the holding of seasonal sacrifices (*cāturmāsyāni*), the full-moon sacrifices, the *soma* feast lasting a year, the yearly *sattras* and so on involved knowledge of a workable calendar and presupposed a class of priests skilled in time-reckoning.

In the sacred literature of the Hindus, the Jainas and the Buddhists, such a skilled priest has been referred to as 'astronomer' and his science 'astronomy' (*jyotiṣa*). In the *Muṇḍaka Upaniṣad*[a] astronomy is included in the list of several branches of Vedic studies. The *Chāndogya Upaniṣad*[b] has it that Nārada, upon being interrogated by Sanat Kumāra as to the range of his knowledge, replied, 'I have learnt the *Ṛgveda*, the *Yajurveda*, the *Sāmaveda* and the fourth the *Atharvaveda*; the *Itihāsa* and the *Purāṇa* as the fifth *Veda*; grammar, the science *par excellence*; the obsequies of Manu; the art of computation; omens; the revolutions of periods; speech; ethics; scriptures; sciences appendant on holy writings (accentuation, prosody, etc.); the abjuration of spirits; the military science; *astronomy*; snake-charming; music and mechanical arts (sciences of the demi-gods).' In explaining the scope of astronomy, the *Vedāṅga Jyotiṣa* states: 'The Vedas are revealed for the purpose of performing sacrificial rites; these rites are laid down in order of time. Therefore, he who is versed in astronomy, the science of the reckoning of time, knows the sacrifices.' In the *Brāhmaṇa* literature, we come across the term *nakṣatra-darśa* meaning 'a star gazer' or 'a gazer at the lunar mansions'. This term has also been used sometimes to mean an astrologer. Another term used to refer to an astronomer is *gaṇaka* which literally means 'a calculator' or 'a mathematician'. The use of these two terms appears to imply the study of astronomy both from the practical (observation of stars) and theoretical (calculation) considerations.

The Jainas also claim considerable antiquity for their interest in, and study of, astronomy. The four branches of their canonical texts include *gaṇitānuyoga* (principles of mathematics), *saṃkhyāna* (arithmetic) and *jyotiṣa* (astronomy).[c] Like the Brāhmaṇas, the Jainas, too, demanded of their priests great proficiency in astronomy for the proper observance of

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[a] *Muṇḍ. Up.*, i. 1.5.
[b] *Chānd. Up.*, vii. 1–4.
[c] *Bhag. Sū.*, 90; *Uttar. Sū.*, xxv. 7.8.38.

their religious ceremonies. The Buddhists did not evince much interest in astronomy due probably to the degeneration in their time of astronomy into astrology, and to the difficulty of distinguishing between the two. We find in their literature the term *nakṣatra-pāṭhaka* (a reader of stars) which refers both to an astronomer and an astrologer. Buddha referred to astronomy and astrology as low forms of arts (*tiracchāna vijjā*) and advised Buddhist monks to refrain from the study of astronomy.[a] This opinion, however, was modified later on and the *bhikṣus* dwelling in the woods were advised to learn the elements of astronomy.

From what has been stated above, and will appear in what follows, there is no doubt that astronomy was cultivated to a considerable extent in India in the Vedic times. The selection of a few fixed stars for the development of a system of lunar mansions, the fixation of a *sāvana* year of 360 days, based upon the variation of the length of day, the elaboration of a quinquennial cycle with intercalary months, going back to the time of the *Ṛgveda*, the idea of the four mundane ages and several other findings abundantly show their interest and proficiency in astronomy. This Brāhmaṇic interest and proficiency did not also escape the notice of foreign observers and writers, for Megasthenes found the *yuga* system flourishing in full perfection and Strabo referred to astronomy as a favourite occupation of the Brāhmaṇas.[b]

ASTRONOMICAL KNOWLEDGE AS REVEALED IN THE *SAṂHITĀS*, *BRĀHMAṆAS* AND *SŪTRAS*

Before summarizing the astronomical information contained in this vast body of the sacred literature, a few general remarks may be made here. Of the various sacerdotal families such as those of Gṛtsamada. Viśvāmitra, Vāmadeva, Atri, Bharadvāja and Vaśiṣṭha, who originated some of the oldest hymns, the family of Atri was probably distinguished for their interest in astronomy. Atri's name is frequently mentioned in connection with eclipse hymns both in the *Saṃhitās* and the *Brāhmaṇas*. The *Sāmaveda* and its *Brāhmaṇas* and *Sūtras* are full of interest from the viewpoint of calendrical astronomy because of their fuller treatment of *gavām ayana* and the *sattras* of various durations, built round the daily progress of the sun. The various recensions of the *Yajurveda* are by far the most important of this class of literature from the viewpoint of the early history of Hindu astronomy. While the *nakṣatras* are doubtless mentioned in the *Ṛgveda*, their whole series, numbering 27 or 28 and headed by *Kṛttikās*, turns up for the first time in the recensions of the *Yajurveda*. These texts are again repositories of several mythologies developed around stellar constellations. The details of *darśapūrṇamāsa*, i.e. the new- and full-moon sacrifices, the *cāturmāsya* or four-monthly sacrifices, seasons, months

[a] Rhys Davids, II, pp. 20 ff.; Oldenberg, *VP. Culla.*, v. 33.3.
[b] Weber, p. 246.

and month names, are here met with. The importance of the winter solstice is emphasized through the *mahāvrata* rites which are also dealt with at length in the *Brāhmaṇas* of the *Sāmaveda*. The number 10,800 used to specify the bricks required for some types of altars appears to be related to the length of the astronomical *yuga* characteristic of the later *Siddhānta-jyotiṣa* texts. The *gavām ayana* and the *sattras*, probably taken over from the *Sāmaveda* and its *Brāhmaṇas*, find lengthy treatment in these *Yajus* texts. The *Atharvaveda* offers little assistance towards our understanding of the nature and extent of the Vedic astronomy. Nevertheless, it does contain stray passages of astronomical consequence, such as the solar eclipse, the mention of *Rāhu* for the first time, intercalation with a thirteenth month and a list of 28 *nakṣatras* including *Abhijit*. Finally, its cosmogonic and theosophic hymns addressed to Goddess Earth, the glorification of the sun, and the personification of time as a primordial power have also some relevance to this study.

The *Brāhmaṇas* are systematized theological works composed for the main purpose of elucidating the sacrificial texts and explaining the origin and hidden meaning of sacrifices. Each *Saṃhitā* gave rise to a number of *Brāhmaṇas*. In this way astronomical ideas and precepts embedded in the *Saṃhitās* assumed clearer perspective through Brāhmaṇic interpretations. As the materials of the *Saṃhitās* and the *Brāhmaṇas* constitute the basis of the *sūtras*, passages in them of astronomical import have received fresh treatment and sometimes further elaboration at the hands of the *sūtrakāras*. Such is particularly the case with regard to the Vedic calendars. Although the elements and suggestions of such calendars are met with in the *Vedas* proper, different modes of year-reckoning and calendar-keeping appear clearly in the *sūtras*. The *Lāṭyāyana Śrautasūtra* and the *Nidānasūtra* of the *Sāmaveda* are particularly important for this purpose. The *Śulba-sūtras* forming part of the *Kalpasūtras*, as we shall see in the section on mathematics, are important as the oldest Indian works on geometry. Finally, we have two *Jyotiṣa-Vedāṅgas*, one in the *Yajurveda* recension containing 43 verses and the other in the *Ṛgveda* recension containing 36 verses, dealing exclusively with astronomy.

THE SUN, THE MOON, THE EARTH AND PLANETS

The Sun

From the Ṛgvedic times the universe was regarded as divided into three distinct regions, the earth (*pṛthivī*), the firmament (*antarikṣa*) and the heaven (*dyaus*). Each region again had a threefold subdivision. The sun during its sojourn through the universe illuminates and sustains all these regions and their subdivisions. These ideas have been repeatedly expressed in several hymns and verses of the *Ṛgveda*, such as 'the sun hath filled the air and earth and heaven',[a] 'Ye Gods who yonder have your home in the three lucid realms of heaven',[b] and more fully elsewhere.[c]

[a] *ṚV.*, I. 115.1. [b] *ṚV.*, I. 105.5. [c] *ṚV.*, IV., 54.2–7.

The 'threefold earth', the 'triple sphere of light' and similar threefold division of the intermediate region, the sky, have been further elaborated in the *Brāhmaṇas,* as witness the following passage of the *Pañcaviṃśa Brāhmaṇa* :[a]

> 'Through fire, earth and plants, thereby this world is threefold: through wind, intermediate region and birds, thereby that world is threefold, which stands between; through sun, sky and stars, thereby yonder world is threefold.'

The Ṛgvedic verses also bring out very clearly the important part played by the sun as a beneficial power in the Vedic mythology and also its various roles in nature. By its light it not only reveals the worlds, but regulates them, and sustains life on the earth. Although it illuminates the worlds, it also causes the constellations with their weak beams to pass away, like thieves, before its all-beholding rays of light.[b] These rays of light are seven in colour, for 'where these seven rays are shining, thence my house and family extend'[c] and are often likened to the sun god's 'bay coloured horses, bright, changing hues, which speed round earth and heaven.'[d]

As to its regulating powers in nature, it is the cause of the flowing of the floods and the winds and is the maker of time through the alteration of day and night, the twilight, month and year. Regarding day and night the *Aitareya Brāhmaṇa*[e] of the *Ṛgveda* states that the sun neither sets nor rises. After reaching the end of the day, it only changes about and in the process makes night below and day on the other side. After reaching the end of the night, the sun makes day below and night on the reverse side. According to another naïve interpretation, the sun was here represented as possessing a bright and a dark face; at the end of the day, the sun's dark face was turned towards the earth making night below and the bright face upwards illuminating the stars in the upper regions of the heaven.

The Sun's Path, the Ecliptic

There are several references in the *Ṛgveda* and in the *Brāhmaṇas* of the later ages to the sun's path through the heavens. Varuṇa, the chief of the Lords of natural order, has made a spacious pathway for the sun to travel.[f] This path called *ṛta* is easy to find. Elsewhere, it is referred to as Aryaman's mighty path: 'How may we pass the wicked on the path of mighty Aryaman? Mark this my woe, ye Earth and Heaven.'[g] The *Pañcaviṃśa Brāhmaṇa* speaks of this path as follows: 'By means of this (rite), Aryaman gained the world. The path called Aryaman's path is the path leading to the Gods. They who undertake this (rite) reach the path leading to the Gods.'[h] According to the *Śatapatha Brāhmaṇa*, 'to Bṛhaspati belongs that upper region, and there above lies that path of Aryaman (the

[a] *Pañc. Br.*, x. 1.1.
[b] *ṚV.*, I. 50.2.
[c] *ṚV.*, I. 105.9.
[d] *ṚV.*, I. 115.3.
[e] *Ait. Br.*, iii. 44.4.
[f] *ṚV.*, I. 24.8.
[g] *ṚV.*, I. 105.6.
[h] *Pañc. Br.*, xxv. 12.2.3.4.

sun).'[a] These passages have been interpreted in two ways. Weber regarded Aryaman's path as the milky way; Hillebrandt, Ludwig and others as the ecliptic. Ludwig further traced the inclination of the ecliptic to the equator in another passage of the *Ṛgveda* in which the *Ṛbhus* are described as wandering afar in their path.

From the way Aryaman's path is described it is not immediately easy to associate it with the ecliptic, but such inference is quite possible from the knowledge of the Vedic Hindus about the sun's annual revolution, its going northward (*uttarāyaṇa*) for half of the year and southward (*dakṣiṇāyana*) for the remaining half, the references to solstices and other related matters. Of further significance in this regard is the occurrence of such terms as *devayāna* and *pitṛyāna* from which Tilak attempted to derive the knowledge of equinoxes in the Vedic times and therefore of the celestial equator, the ecliptic and their inclination.[b]

The Moon

The moon, the next most conspicuous object in the night sky, receives such appellations as *candra, candramas* and *soma.* It has no light of its own, but assumes 'the brilliancy of the sun'[c] or 'is adorned with Sūrya's arrowy beam',[d] that is it shines with the borrowed light of the sun. The phases of the moon are described by saying that the moon, 'born afresh, is new and new for ever'.[e] Some of its phases received special names and personifications. Thus, the day before the new moon was called *sinīvālī,* the new moon day *kuhū,* the day preceding the full moon *anumati* and the full moon day *rākā.* An allegorical description of the sun swallowing the moon on the new moon day so that it can neither be seen in the eastern nor the western sky is preserved in the *Śatapatha Brāhmaṇa*[f] as follows:

> 'Now the one that burns there (viz. the sun) is, assuredly, no other than Indra, and that moon is no other than Vṛtra. But the former is of a nature hostile to the latter, and for this reason, though this one (the moon, Vṛtra) had previously (to the night of new moon) risen at a great distance from him (the sun, Indra), he now swims towards him and enters into his open mouth.
>
> 'Having swallowed him, he (the sun) rises; and that (other) one is not seen either in the east or in the west...
>
> 'Having sucked him empty, he throws him out; and the latter, thus sucked out, is seen in the western sky, and again increases; he again increases to serve that (sun) as food...'

The above passage sets forth the moon's elongation from the sun, its true motion from west to east and the cause of the new and full moon.

The interval between the consecutive new moons or full moons was seized upon at quite an early date as a natural unit of time, the month,

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[a] *Śat. Br.*, v. 3.1.2.
[b] Tilak, pp. 112 ff.
[c] *ṚV.*, IX. 71.9.
[d] *ṚV.*, IX. 76.4.
[e] *ṚV.*, X. 85.19.
[f] *Śat. Br.*, i. 6.4.18–20.

in much the same way as it was done by the people of other culture areas, the Babylonians, the Greeks and so on. From several verses and passages stating that the year consists of 360 days and of 12 months, it appears that a month of 30 days was widely accepted in the time of the *Saṃhitās* and the *Brāhmaṇas*. The month was again divided into two natural halves, the light half (*śukla*) from new to full moon and the dark half (*kṛṣṇa*) from full to the new moon. The Ṛgvedic bard had thus no hesitation in proclaiming:[a]

> 'Twelve are the fellies, and the wheel is single; three are the naves. What man hath understood it?
> 'Therein are set together spokes three hundred and sixty, which in no wise can be loosened.'

The moon's synodic period was later on more correctly given as 29½ days. Its sidereal period lying between 27 and 28 days appears to have been correctly formulated in the days of the early *Saṃhitās* as is clear from the development of the 27 or 28 *nakṣatra* system.

The Solar Eclipse

Observation of the solar eclipse is recorded in several places in the Vedic literature in the form of the well-known Svarbhānu legend. According to its earliest Ṛgvedic version,[b] Svarbhānu, the *asura*, pierced the sun with darkness so completely that the bewildered inhabitants on the earth did not know where they were standing. Then Atri, with the power of his prayers, caused Svarbhānu's magic arts to disappear and restored the sun to its brilliance. The Svarbhānu legend and Atri's part in ending the eclipse appear in a number of places in the *Pañcaviṃśa Brāhmaṇa*, of which a typical description runs as follows:[c]

> 'The Daemoniac Svarbhānu struck the sun with darkness; the Gods did not discern it (the sun hidden as it was by darkness): they resorted to Atri; Atri repelled its darkness by the *bhāsa*. The part of the darkness he first repelled became a black sheep, what (he repelled) the second time (became) a silvery (sheep), what (he repelled) the third time (became) a reddish one, and with what (arrow) he set free its original appearance (colour), that was a white sheep.'

The interesting feature of the above passage is the detailed observation of the change of colour in the sun's disc during the progress of an eclipse.

The frequent and consistent references to Atri in connection with eclipses doubtless indicate a class of Brāhmaṇa priests skilled in eclipse observations and in astronomy in general. The eclipse hymns of the *Ṛgveda* contain an expression *turīyeṇa brahmaṇā* which, according to some scholars, meant a kind of quadrant; but such interpretation is far-fetched.

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[a] *ṚV.*, I. 164.48; Eng. trans. by Griffith.
[b] *ṚV.*, V. 40.5–9.
[c] *Pañc. Br.*, vi. 6–8; Eng. trans. by Caland.

The Earth

It is difficult to say definitely if the Vedic Hindus regarded the earth as spherical. The sphericity of the earth may be implied in such casual statements as the earth is freely suspended in air,[a] the dawn precedes the sunrise[b] and the like. In the cosmogonic and theosophic hymns of the *Atharvaveda*[c] the earth and the heaven have been imagined as constituting two hemispheres which the Brahmacārin guards with his creative power. This and statements like the placing of fire between two receptacles or the union of two *agnis* between the two hemispheres of the world suggest terrestrial sphericity, later on accepted uniformly in Hindu astronomical texts.

The Planets

The study of planets appears in late astronomical works. The *Vedāṅga Jyotiṣa* does not mention them. But this does not mean that the Vedic Hindus were altogether unacquainted with planets. Weber did not notice the mention of planets in any texts earlier than the *Taittirīya Āraṇyaka*. In the *Maitrāyaṇī Upaniṣad*, planets (*graha*) are mentioned. In the early astronomical *saṃhitās*, planets are mentioned in the context of their astrological implications. Planet worship is established in Yājñavalkya's law-book and is mentioned in the epics, and in the dramas of Kālidāsa and in the *Mṛcchakaṭika*. Opinion, however, differs as to whether earlier Vedic works contain any evidence of the knowledge of planets. The 7 *ādityas* mentioned in the *Ṛgveda*[d] were interpreted by Oldenberg as referring to the sun, the moon and the 5 planets. The number 34 used to express, in hymn X. 55.4, the lights with which Indra looks around him and, in hymn I. 162.18, the ribs of the sacrificial horse has been explained by Ludwig as referring to the sun, the moon, 5 planets and 27 *nakṣatras*.

More convincing perhaps is the association of Bṛhaspati, Lord of Prayer, with the planet Jupiter. The *Taittirīya Brāhmaṇa* refers to the conjunction of Bṛhaspati with the *nakṣatra Tiṣya*. The planet's first birth 'from mighty splendour in supremest heaven' is also referred to in the *Ṛgveda*. The *Ṛgveda* and the *Brāhmaṇas* contain the words *śukra*, *manthin* and *vena*, and attempts have been made to associate them with the planet Venus; but this interpretation has not found acceptance with all scholars.

Rāhu and Ketu

To the seven planets, including the sun and the moon, the Indians added *Rāhu* and *Ketu*, to formulate their *Rāhu-Ketu* theories of eclipses. The word *Rāhu*, in the sense of a planet, appears in the *Atharvaveda* and the *Chāndogyopaniṣad* apparently with no astronomical meaning, but in the *Yājñavalkyasmṛti* it does so in the astronomical sense. The word

[a] *ṚV.*, IV. 53.3.
[b] *ṚV.*, I. 123.
[c] *AV.*, XI. 5.8–11.
[d] *ṚV.*, IX. 114.3.

Ketu also appears in the *Atharvaveda* in the sense of any unusual or striking phenomenon such as comet, meteor or a falling star. Astronomical *saṃhitās*, however, do not mention *Ketu* as a cause of eclipse. *Rāhu* and *Ketu*, along with planets, are mentioned in the *Mahābhārata*, though *Ketu* is omitted in the *Rāmāyaṇa*. From Varāhamihira onwards, in true astronomical circles, *Rāhu* and *Ketu* meant the ascending and the descending node respectively of the moon.

The ingenious *Rāhu-Ketu* theory of eclipse travelled from India to China and appeared in a Chinese astronomical text *Chiu Chih*. This *Chiu Chih* was the Chinese version of an Indian calendrical work called *Navagraha* and its translator was the well-known Tantric-Buddhist astronomer Chhuthan Hsi-Ta who flourished at the Thang court during the first quarter of the eighth century A.D.

THE STARS, THE *NAKṢATRA* SYSTEM AND THE LUNAR ZODIAC

Unlike the Babylonians or the Chinese, the ancient Indian astronomers were not particularly interested in the study of stars as such and in the preparation of star catalogues. They were primarily interested in the study of the motions of the sun and the moon with a view to developing a workable calendar. As such their interest in stars and constellations largely centred round those which lie along or near the ecliptic. By a careful selection of suitable stars and constellations they were able to provide a stellar frame of reference against which to follow and measure planetary motions. A number of ancient civilizations—the Indian, the Chinese, the West Asian and the Egyptian—developed and perfected such a stellar frame of reference to mark the path of the sun and the moon. The system came to be known as that of the *nakṣatras* among the Indians, of the *hsius* among the Chinese, of *manāzil* among the Arabs and so on.

The origin of the Indian *nakṣatra* system has been traced to the *Ṛgveda*, where the term *nakṣatra* has been used both in the sense of stars and lunar mansions. In the former sense it appears in I. 50.2; VII. 86.1; X. 68.11 and in several hymns. The sun is also sometimes identified with stars.[a] In the sense of lunar mansions, at least two *nakṣatras* are clearly mentioned, namely *Maghā* (*Aghā*) and *Phalgunis* (*Arjunis*), as in the thirteenth verse of the sun's bridal hymn 85 in the tenth *maṇḍala*:

> 'The bridal pomp of Sūrya, which Savitar started, moved along.
> In Maghā days are oxen slain, in Arjunis they wed the bride.'[b]

Although other *nakṣatras* are not specifically named, Ludwig, Zimmer and others held that 27 *nakṣatras* were already known when the *ṛcas* were formed and included in the number 34 (the sun, the moon, 5 planets and 27 *nakṣatras*) previously referred to. Their use in the sense of lunar mansions is also stated clearly in another expression: 'Thus Soma in the midst of all these constellations hath his place.'[c]

[a] *ṚV.*, III. 54.19. [b] Eng. trans. by Griffith. [c] *ṚV.*, X. 85.2.

TABLE 2.1

Nakṣatra list in the Vedic Saṃhitās, the Vedāṅga Jyotiṣa and in the Sūrya-siddhānta

No. in order	*Taitt. Saṃ.* (IV. 4.10)	*Maitrā. Saṃ.* (II. 13.20)	*Kāṭh. Saṃ.* (XXXLX, 13)	*Atharvaveda*	No. in order	*Vedāṅga Jyotiṣa* (18)	No. in order	*Sūrya-siddhānta* (VIII. 2–21)
1.	Kṛttikās	Kṛttikās	Kṛttikās	Kṛttikās	1.	Bharaṇyaḥ†	1.	Aśvinī
2.	Rohiṇī	Rohiṇī	Rohiṇī	Rohiṇī	2.	Kṛttikā	2.	Bharaṇī
3.	Mṛgaśīrṣa	Invagā	Invakā	Mṛgaśīras	3.	Rohıṇī	3.	Kṛttikā
4.	Ārdrā	Bāhu	Bāhu	Ārdrā	4.	Mṛgaśīrṣa	4.	Rohiṇī
5.	Punarvasū	Punarvasū	Punarvasū	Punarvasū	5.	Ārdrā	5.	Mṛgaśīrṣa
6.	Tiṣya	Tiṣya	Tiṣya	Puṣya	6.	Punarvasū	6.	Ārdrā
7.	Āśreṣās	Āśleṣās	Āślesās	Āśleṣās	7.	Pusya	7.	Punarvasu
8.	Maghās	Maghās	Maghās	Maghās	8.	Āśleṣā	8.	Puṣya
9.	Phalgunī	Phalgunīs	Phalgunīs	Pūrvā Phalgunyau	9.	Maghā	9.	Āśleṣā
10.	Phalgunī	Phalgunīs	Uttaraḥ Phalgunīs		10.	Pūrvaphalgunī	10.	Maghā
11.	Hasta	Hasta	Hastau	Hasta	11.	Uttaraphalguni	11.	Pūrvaphālgunī
12.	Citrā	Citrā	Citrā	Citrā	12.	Hasta	12.	Uttaraphālguni
13.	Svātī	Niṣṭya	Nisṭya	Svātī	13.	Citrā	13.	Hasta
14.	Viśākhe	Viśākhā	Viśākhā	Viśākhe	14.	Svātī	14.	Citrā
15.	Anūrādhās	Anūrādhā	Anūrādhās	Anūrādhā	15.	Viśākhā	15.	Svātī
16.	Rohiṇī	Jyeṣṭhā	Jyeṣṭhā	Jyesṭhā	16.	Anurādhā	16.	Viśākhā
17.	Vicṛtau	Mūla	Mūla	Mūla	17.	Jyeṣṭhā	17.	Anurādhā
18.	Aṣāḍhās	Aṣāḍhās	Aṣāḍhās	Pūrva Aṣāḍhās	18.	Mūla	18.	Jyeṣṭhā
19.	Aṣāḍhās	Aṣāḍhās	Uttarā Aṣāḍhās	Uttarā Aṣāḍhās	19.	Pūrvāṣāḍhā	19.	Mūla
20.	*	Abhijit	—	Abhıjıt	20.	Uttarāṣāḍhā	20.	Pūrva Aṣāḍhā
21.	Śroṇā	Śroṇā	Aśvattha	Śravaṇa	21.	Śravaṇa	21.	Uttarā Aṣāḍhā
22.	Śraviṣṭhās	Śraviṣṭhās	Śraviṣṭhās	Śraviṣṭhās	22.	Dhaniṣṭhā	22.	Abhijit
23.	Śatabhiṣaj	Śatabhiṣaj	Śatabhiṣaj	Śatabhiṣaj	23.	Śatabhiṣaj	23.	Śravaṇa
24.	Proṣṭhapadās	Proṣṭhapadās	Proṣṭhapadā	Dvayā Proṣṭhapadā	24.	Pūrva Bhādrapadā	24.	Śraviṣṭhā
25.	Proṣṭhapadās	Proṣṭhapadās	Uttare Proṣṭhapadās		25.	Uttara Bhādrapadā	25.	Śatabhiṣaj
26.	Revatī	Revatī	Revatī	Revatī	26.	Revati	26.	Pūrva Bhādrapadā
27.	Aśvayujau	Aśvayujau	Aśvayujau	Aśvayujau	27.	Aśvayujau	27.	Uttara Bhādrapadā
28.	Apabharaṇis	Bharaṇis	Apabharaṇis	Bharaṇyas			28.	Revatī

* *Abhijit* is, however, mentioned in the *Taittirīya Brāhmaṇa*.

† In the *Vedāṅga Jyotiṣa*, the head of the *nakṣatras* is not mentioned. From the statement that solstices coincide with *Dhaniṣṭhā* and *Āśleṣā*, vernal equinox appears to coincide with *Bharaṇyaḥ* and so the list has been shown in the table starting with this *nakṣatra*.

The full list of 27 or 28 *nakṣatras* headed by *Kṛttikās* appears in the various recensions of the *Black Yajurveda* and in the *Atharvaveda*. Table 2.1 gives the full list of *nakṣatras* as found in the *Saṃhitās*, in the *Vedāṅga Jyotiṣa* and in later astronomical *siddhāntas* (the list given in the *Sūrya-siddhānta* is given here).

It is clear from the table that the *nakṣatra* names have remained practically the same since their formulation in the Vedic times. The *nakṣatra Abhijit* does not appear in all the lists, making the number sometimes 27 and sometimes 28. It appears only in the *Maitrāyaṇī Saṃhitā*, the *Atharvaveda*, the *Taittirīya Brāhmaṇa* and some *Siddhāntic* texts, but the star does not have associated with it any *nakṣatra* space. This *nakṣatra* space requires some clarification. The term *nakṣatra* has been used to indicate both asterisms, stars or star-groups, and any of the 27 equal divisions of the ecliptic, each distinguished by a determinant star (*yoga tārā*). Derived from *nakta-tra*, it means 'guardian of night', that is stars or star-groups, and in this sense the word must have been used at the beginning. Later on, *nakṣatra* meant one of the 27 equal parts, that is a space of 13° 20′ or 800′ of the ecliptic. In the *Sūrya-siddhānta* and such later astronomical works, a *nakṣatra* division of 800′ has been clearly defined, and the positions of the determinant or junction stars have been given in degrees and minutes with respect to the starting point of the *nakṣatra* concerned. These values have been given in accordance with a system of polar coordinates—the polar longitudes (*dhruvaka*) and latitudes (*śara*)—from which true longitudes and latitudes or right ascensions and declinations can be calculated for comparison with current stellar positions. Colebrooke, Burgess and Whitney and other historians of Hindu astronomy have carried out these conversions and identified Hindu *nakṣatras* with those given in modern star catalogues. Some of these identifications, the Hindu stellar configurations and the legends built round them are summarized below.

The Nakṣatras and Constellations

Kṛttikā is a group of 6 or 7 stars known as Pleiades; the dominant star is η Tauri (magnitude 3). According to the *Yajurveda*, this group consists of 7 stars and, according to al-Bīrūnī and other texts, of 6 stars. It corresponds to the Chinese *hsieu Mao* and the *manāzil ath-Thuraiyā*. *Rohiṇī* has been identified with Aldebaran or α Tauri (magnitude 0·9). *Mṛgaśīrṣa* figured as the 'antelope's head' is a group of 3 stars, λ, ϕ^1 and ϕ^2 in Orion. Around *Rohiṇī* and *Mṛgaśīrṣa* developed the Prajāpati legend given in the *Aitareya* and the *Śatapatha Brāhmaṇa*. Lord Prajāpati once fell in love with his own daughter *Rohiṇī* and in the form of a deer pursued her as she was running away in the form of a female deer. Enraged at such incestous chase, the gods ordered Rudra to stop the chase, whereupon Rudra assumed the form of a hunter (*Mṛgavyādha*) and pierced Prajāpati with his arrow. The head of the antelope with the arrow sticking to it became the constellation *Mṛgaśīrṣa*.

Punarvasū is the twin stars Castor and Pollux in the constellation of Gemini. *Puṣya* is a group of 3 to 5 faint stars in Cancri. *Āśreṣās* (or *Āśleṣās*) and *Maghā* each is a cluster of 5 to 6 stars, the former in Hydrae and the latter in Leonis. *Phalgunī* is a double-star constellation in Leo. The five-starred *Hasta*, meaning hand, is in Corvus. *Citrā* is the readily identifiable brilliant star α Virginis or Spica of the first magnitude. So also in *Niṣṭyā* or *Svātī*, the brilliant α Bootis or Arcturus (magnitude 0·0). To *Viśākhā* are attached sometimes 2 and sometimes 4 stars in Librae and to *Anurādhā* 4 stars in Scorpionis. *Jyeṣṭhā* is a trio in Scorpio, of which the determinant star is Antares or α Scorpionis (magnitude 0·8).

Abhijit (determinant α Lyrae) has no *nakṣatra* space assigned to it in the ecliptic. Its 3 stars form a triangle in Lyra. It is mentioned only in texts giving a list of 28 *nakṣatras*, but not in those giving one of 27. This might mean a later addition to, or even dropping out from, the original list and received much attention in connection with the question of origin of the *nakṣatra* system and its relationship with similar systems in other civilizations.

Śroṇā or *Śravaṇa* (determinant α Aquilae) is a constellation of 3 stars in Aquilae; the four-starred *Dhaniṣṭhā* is in Delphinus; and *Śatabhiṣaj*, meaning 'having one hundred physicians', is a thickly studded cluster in Aquarii. The two *Bhādrapadās* are twin star-groups in Pegasi. *Revatī*, a group of 32 stars, has its determinant star in ζ Piscium (magnitude 5·5). The end of this *nakṣatra* (according to the *Sūrya-siddhānta*, 13° 10′ from the beginning of *Revatī* or 359° 50′ with respect to the First Point of Aries) or the beginning of *Aśvinī*, the next *nakṣatra* in Aries marked the initial point of the Hindu sphere about A.D. 572.

The Nakṣatra and Lunar Mansions of Other Nations

We have said that a number of nations of antiquity, notably the Chinese, the Arabs and the Babylonians, followed a system of lunar mansions analogous to that of the *nakṣatras*. Whether all these systems had a common origin or had developed independently became naturally enough a subject of considerable discussion and controversy. The Sinologists, the Indianists and the Assyriologists laid powerful claims on the anteriority as well as the originality of their respective systems, and not unoften suggested borrowing by other nations of the system they considered native to the culture area of their preference. But the question has still remained very much an open one.

The Hsius

The Chinese *hsius* were originally selected to mark the equator and facilitate observation of the culmination of stars.[a] In their system a series of circumpolar stars were keyed to equatorial stars so that, by observing the lower meridional transits of the former, those of the latter below

[a] Needham, III, pp. 242–52.

the horizon could be readily ascertained. The declination circles passing through the selected equatorial and the corresponding circumpolar stars divided the equator into a number of unequal segments called the *hsius*. At least two of the *hsiu* stars, the Bird Star (α Hydrae) and the Fire Star (π Scorpii), have been recognized in the carvings of the oracle-bones belonging to the Shang period (1500 B.C.). The *Book of Odes* (*Shih Ching*) believed to have come down from the eighth or ninth century B.C. records about 8 *hsius*. The use of four quadrantal *hsius*, e.g. *Fang* (middle of Eastern Palace), *Hsü* (middle of Northern Palace), *Mao* (middle of Western Palace) and *Hsing* (middle of Southern Palace), is met with in the *Historical Classic* (eighth to fifth century B.C.). *The Lesser Annuary of the Hsia Dynasty* (fourth century B.C.), a kind of farmer's calendar, mentions all the four quadrantal stars plus two more, *Wei* (μ Scorpii) and *Liu* (δ Hydrae). A fuller list of *hsius*—23 out of 28—is given in the *Records of Rites of Younger Tai* (first century B.C.). The full list of 28 *hsius*, however, appears for the first time in *Huai Nan Tzu* (160 or 150 B.C.) and, more importantly, as a lunar zodiac and not as equatorial stars of earlier records.

Thus the full list of 28 *hsius* appeared in China several centuries later than did the *nakṣatra* list in the various recensions of the *Black Yajurveda*. As a lunar zodiac, the Chinese system did not emerge before the fourth century B.C., if not later. As to the *hsius* themselves, many of them differ importantly from the *nakṣatras*. Nine *nakṣatras* agree with the corresponding *hsius* both in regard to their determinant stars and more or less with the number of stars attached to the constellations. For 11 *nakṣatras*, the determinants are different although they belong to the same constellations. For the remaining 8 *nakṣatras* and *hsius*, the determinant stars were selected from different constellations.

The Manāzil

The Arabian *manāzils*, 28 in number, agree on the whole with the Indian *nakṣatras*. Their lunar zodiac is headed by *ash-Sharaṭān*, the first *manāzil* corresponding to *nakṣatra Aśvinī* which marked the point of intersection between the equator and the ecliptic about the fifth or sixth century A.D. As many as 19 *manāzils* agree with the corresponding *nakṣatras*; there are discrepancies with regard to *Ārdrā*, *Hasta*, *Svātī*, *Abhijit*, *Śroṇā*, *Śraviṣṭhā* and *Revatī* *vis-à-vis* the corresponding *manāzils*. Weber at one time believed that the Arabian lunar stations had been derived directly from the Indian *nakṣatras*. The recorded evidence of transmission of Indian astronomical texts, particularly the *Siddhāntas*, makes such a view attractive; but, as Filliozat (3) has pointed out, all this, even the close resemblance between the two systems, does not *ipso facto* prove an Arab borrowing from India. Long before the beginning of active Arab scientific contacts with India during the reign of the Abbāsid Caliphs, the *manāzils* found mention in the al-Qur'ān (x. 5; xxxvi. 39). The *Fihrist* records that the ancient Harranites had a custom of visiting their temples for offering sacrifices to the moon and performing other religious ceremonies on the

27th or 28th day of each month, from which Weber inferred far-fetchedly knowledge of lunar mansions among the Harranites.[a] Of greater consequence perhaps were his interpretations of the Hebrew word *mazzaloth* or *mazzaroth* in the Book of Job (38. 32) and Book of Kings (23. 5) to mean *manāzil* and suggestion of Chaldean origin. Derivation of the *manāzil* from an Iranian system was attempted by Leopold de Saussure.

The Question of Babylonian Origin of Lunar Mansions

Weber, Whitney and later on Hommel and other Assyriologists favoured the theory of a Babylonian origin of lunar mansions. The Babylonians, at quite an early date, developed the knowledge of constellations and its use in following the motions of the sun, the moon and planets. By about 1100 B.C. they had divided the sky into three zones of 12 sectors each, these sectors containing the names of constellations, planets and simple numbers in arithmetic progression. Moreover, they assigned 3 stars or constellations to every month, which indicates an attempt to obtain some kind of correlation of months to constellations.

A true zodiacal scheme is implied in the important series of texts known as ^{mul}APIN dated about 700 B.C., but based on older materials. These tablets give the names of about 18 constellations more or less along the ecliptic. Here are some of them: ^{mul}mul (Pleiades), ^{mul}gu$_4$.an.na (Taurus), ^{mul}UR.GU.LA (Leo), ^{mul}ab.Sín (Spica), ^{mul}PA.BIL.SAG (Sagittarius) and so on. Later texts appear either to multiply or to reduce the number of stars with a view to defining planetary positions more accurately and, in this manner, their number gradually rose to 33 or more as recorded in Babylonian ephemerides.

The first attempt to construct out of 33 or 36 Babylonian normal stars a lunar zodiac composed of 24 ecliptic stars was due to Fritz Hommel of Munich.[b] He compared the Babylonian stars with the Arabian *manāzils*, found agreement in respect of 16 stations and concluded that the *manāzils* were based on the more ancient Babylonian scheme. On the basis of the theory of common origin, Hommel's work was taken to be an important argument in favour of the derivation of the various lunar zodiac schemes from the Babylonian. Thibaut raised a number of objections to such a view.[c] Between the *nakṣatras* and the Babylonian ecliptic stars, agreement has been noticed in the case of about one-third of the total number. *Mṛgaśīrṣa*, *Ārdrā*, *Āśreṣās*, *Hasta*, *Mūla*, *Abhijit* and *Śraviṣṭhās* differ completely from their opposite numbers in the Babylonian series. Even in the agreement itself there is nothing very surprising if one bears in mind that, in all these separate attempts, the task was the same, namely to select a series of conspicuous asterisms near the ecliptic. In such circumstances it is inevitable that specially bright stars such as α Tauri, β Geminorum, α Leonis, α Virginis, α Scorpionis—all of the first magnitude—

[a] Weber, p. 248. [b] Hommel, pp. 592–619. [c] Thibaut (3), pp. 144–63.

or such well-defined stars such as Pleiades, α and β Geminorum, α and β Librae should be selected.

Another important objection is that the Babylonian series comprises 33 or 36 stars, whereas the *manāzil* consists of 28 and the *nakṣatra* 27 or 28 star-groups. Hommel tried to explain this by guessing that the lunar zodiacs of all nations had originally 24 stars or star-groups only, which were expanded into 27, 28 or even a larger number. The Chinese *hsius*, it is true, had 23 members at some early stage of their development, but such is not the case with either the *manāzil* or the *nakṣatra*, which from the beginning comprised of 27 or 28 stations.

Thus the common origin hypothesis, with Babylon as the centre of diffusion, does not appear to rest on solid ground. The career in Babylon of a lunar zodiac proper is itself doubtful. There is no such doubt about the careers of the *nakṣatras*, the *hsius* or the *manāzils*. Whether all these systems developed independently or had a common origin or to what extent one system influenced the other still remains largely a matter of speculation.

DIVISION OF TIME—DAY, MONTH, SEASONS, VEDIC LUNI-SOLAR CALENDAR, SOLSTICES AND EQUINOXES

The Day

Both 'day' and 'night' appear as natural unit of time in the earliest literary productions of the Indians. Expressions like 'many dawns and nights', 'days subdue the nights' occur in the *Ṛgveda*. As Haug has shown, the day in the Vedic times was generally taken to start and end with the sunset. The civil or natural day from sunrise to sunrise or from midnight to midnight has been called *sāvana* day in later astronomical works. In the *Sūrya-siddhānta*, terrestrial civil days are reckoned from sunrise to sunrise. Āryabhaṭa reckoned it both from sunrise and from midnight at Laṅkā.

Day, that is the bright half, was divided, according to the *Atharvaveda* and the *Taittirīya Brāhmaṇa*, into five parts, e.g. *udyan sūryaḥ* (rising sun), *saṃgava* (gathering of cows), *madhyaṃ-dina* (midday), *aparāhṇa* (afternoon) and *astaṃ-yan* (sunset).[a] Further division of the day into *muhūrtas* and still smaller units has been traced to the *Brāhmaṇa* period. According to the *Śatapatha Brāhmaṇa*,[b] 'there are ten thousand and eight hundred *muhūrtas* in the year (1 day = 30 *muhūrtas*), and fifteen times as many *kṣiprus* as there are *muhūrtas*; and fifteen times as many *idāni* as there are *etarhi*; and fifteen times as many breathings as there are *idāni*'. In the *Sāṅkhyāyana Āraṇyaka*[c] the day is progressively subdivided into *muhūrta*, *kṣaṇa*, *kalā*, *kāṣṭhā*, *nimeṣa* and *dhvaṃsa*. Kauṭilya's *Arthaśāstra* gives *muhūrta*, *nālikā*, *kalā*, *kāṣṭhā*, *nimeṣa*, *lava* and *tuṭa* as various units of time.

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[a] *AV.*, IX. 6.45.
[b] *Śat. Br.*, xii. 3.2.5.
[c] *Sāṅkh. Ār.*, vii. 20.

The experience of the variations of day-length with seasons must have been very ancient, but details of actual measurements and rules for calculating them at any time of the year appear rather late—about the time of the *Vedāṅga Jyotiṣa*. The increase of day-length from winter solstice to summer solstice and the corresponding decrease in the duration of the night are recorded in the *Jyotiṣa*. Here the day has 30 *muhūrtas*, the shortest day-length at the winter solstice is given as 12 *muhūrtas* and the longest at the summer solstice as 18 *muhūrtas*. The total increase in day-length in one *ayana* of 183 days (according to the *Jyotiṣa*, a year has 366 days) being 6 *muhūrtas*, the rate of increase per day is given as 2/61. Weber suspected that the rule found in the *Vedāṅga Jyotiṣa* might have been imported to India from Babylon, for the latitude of which the above statements agree. But the results are also true for latitudes of parts of north-west India and could have been obtained as well by independent observations.

A 'solar' day (*saura-dina*) as a time unit, defined as 360th part of the year, is hinted at in the *Vedāṅga Jyotiṣa* and also given in the *Pañca-siddhāntikā*. The sidereal day, defined as the time taken by the asterisms to complete one revolution, is met with in Hindu astronomy. Garga, in enumerating different kinds of day, makes a clear distinction between a *sāvana* and a 'solar' day (*arka-dina*).

A lunar day or *tithi* is 30th part of one lunation, that is the period in which the moon's elongation increases by 12 degrees. A *pakṣa* or half lunation contains 15 *tithis* which are named by Sanskrit ordinals *prathamā*, *dvitīyā*, etc. The first *tithi* of either *pakṣa* is called *pratipad* and the last or the fifteenth *pūrṇimā* or *amāvāsyā* depending on whether the *pakṣa* is bright or dark. A *tithi* is a calendrical device, but has not much astronomical significance except as an artificial division of the lunation. There is no indication of its development in the period of the *saṃhitās*. It appears fully developed in the *Jyotiṣa* and in the *sūtra* literature. The *Jyotiṣa* and the *sūtras* define a *nakṣatra* day as the thirtieth part of the time required by the moon to complete one revolution through 27 asterisms.

The Month

The reckoning of the month by the moon and the year by the sun was widespread among the ancient civilizations. The concept of the month as a unit of time based on lunation developed in the Vedic times. The *Ṛgveda* describes the moon as 'that which shapes the year'.[a] We have already referred to the riddle hymn describing the year of 360 days as a single wheel with 12 months of 30 days each. Two systems of month-reckoning, e.g. the *amānta* and the *pūrṇimānta*, were in vogue. According to the former, a month has its beginning and end with the new moon; in the latter it is with the full moon. The Greeks, the Romans and the Jews also regarded their lunar months as lasting from the first appearance of the

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[a] *ṚV.*, X. 85.5.

crescent after any new moon till that of the next. Oldenburg was more favourably disposed to the *amānta* system. We also have it from al-Bīrūnī that the *amānta* month was the canonical one. At the same time the derivation of the month names from the *nakṣatras* in which full moon takes place, as also the practice of starting the year with the full moon of the month, leave hardly any doubt that the *pūrṇimānta* reckoning was equally in vogue in the time of the *Brāhmaṇas*.

The names of the lunar months were derived from the *nakṣatras* in which the full moon occurred, e.g. *Phālguna, Caitra, Vaiśākha, Jyaiṣṭha* and so on from the *nakṣatras Phalgunī, Citrā, Viśākhā, Jyeṣṭhā* respectively. Another system of naming months after the seasons of the year also originated during the period of the *Saṃhitās* and the *Brāhmaṇas*. According to the *Black Yajurveda*, such seasonal or solar months are: spring months—*Madhu, Mādhava*; summer months—*Śukra, Śuci*; rain months—*Nabha, Nabhasya*; autumn months—*Iṣa, Ūrja*; Dewy or *Hemanta* months—*Saha, Sahasya*; winter months—*Tapa, Tapasya*. A rough correspondence of lunar and solar months with the seasons was as follows during the period in question:

Lunar months	*Solar months*	*Seasons*
Caitra	*Madhu*	Spring
Vaiśākha	*Mādhava*	
Jyaiṣṭha	*Śukra*	Summer
Āṣāḍha	*Śuci*	
Śrāvaṇa	*Nabha*	Rains
Bhādrapada	*Nabhasya*	
Āśvina	*Iṣa*	Autumn
Kārttika	*Ūrja*	
Mārgaśira (*Agrahāyaṇa*)	*Saha*	Dewy
Pauṣa	*Sahasya*	
Māgha	*Tapa*	Winter
Phālguna	*Tapasya*	

The above correspondence agrees with the statement given in the *Yajus* recensions of the *Jyotiṣa* that *Māgha* and *Tapas* (*māghastapaḥ*) begin together at the commencement of the five-yearly *yuga*. Scholars, however, differ in their opinion on the question of such correspondence. Weber thought *Phālguna* as the first month of spring. Jacobi and Tilak argued that at one time winter solstice coincided with the full moon in *Phalgunī*.

The Seasons

The mention of six seasons in the foregoing paragraph should not be taken to mean that the Vedic Hindus had distinguished them from the very beginning. The *cāturmāsya* or four-monthly sacrifices very strongly

indicate that to all intents and purposes the year was originally divided into three seasons, e.g. the warm, the rainy and the cold. The corresponding sacrifices to be performed to mark the beginning of these three seasons were *Vaiśvadeva, Varuṇapraghāsā* and the *Sākamedha*. Very befittingly, these sacrifices are called *ṛtu mukhāni* in the *Śatapatha Brāhmaṇa*. Two further seasons were in course of time added to the three primitive ones—the autum between the rainy and the cold and the spring between the cold and the warm season. Later on or concurrently, their number was expanded into six by the inclusion of the dewy season (*hemanta* or *śiśira*). The *Śatapatha Brāhmaṇa* mentions sometimes five[a] and sometimes six[b] seasons in the year.

The Intercalary Month

A year of 360 days divided into 12 months of 30 days each raises difficulties in the matter of adjusting the lunar months with the seasons. In the course of a few years the months would be out of step with the seasons. To make them agree with the seasons, it is necessary either to introduce an intercalary month at regular intervals or add the difference of 5 to 6 days to one or more months. There is evidence of both these methods having been tried for purposes of such calendrical adjustments. A year occasionally having a thirteenth or additional month which is produced of itself is referred to in the *Ṛgveda*.[c] The *Atharvaveda* puts it more explicitly as 'He who measures the thirteenth month, fabricated of days and nights, having thirty members—against that God, angered, in this offence.'[d] In the *Black Yajurveda*, the thirteenth month is called *saṃsarpa*, a creeping month, in the *Kāṭhaka*, *malimluca*, and in the *Atharvaveda*, *sanisrasa*. From various stray statements in the *Brāhmaṇas*, it is possible to infer that the Vedic Hindus recognized a lunar year of 354 days ($12 \times 29\frac{1}{2}$), which was adjusted to the sidereal solar year of 366 days (*Vedāṅga Jyotiṣa*) either by adding 12 days each year or a thirteenth month of 30 days every $2\frac{1}{2}$ years.

Vedic Calendars

More detailed information as to the various types of years and months, calendars built round them and different ways of making luni-solar adjustments is available in the *Nidāna Sūtra* and the *Lāṭyāyana Śrautasūtra* of the *Sāmaveda*.[e] The following kinds of year are met with in these *sūtras*:

(*a*) The Sidereal Lunar Year of 324 days—consists of 12 months of 27 days each.

(*b*) The Sidereal Lunar Year of 351 days—consists of 13 months of 27 days each.

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[a] *Śat. Br.*, iii. 1.3.17; 1.4.20.

[b] *Śat. Br.*, ii. 1.1.13; v. 2.1.4; vii. 3.1.35.

[c] *ṚV.*, I. 25.8.

[d] *AV.*, XIII. 3.8.

[e] Shamasastry, pp. 26–32, 45–71.

(*c*) The Synodic Lunar Year of 354 days—consists of 6 months of 30 days each and 6 months of 29 days each.
(*d*) The Civil or *Sāvana* Year of 360 days—consists of 12 months of 30 days each.
(*e*) The Pseudo Solsticial Year—consists of 378 days; here 18 days were added to the third year after two civil years of 360 days each for bringing about agreement between the civil and the sidereal solar year of 366 days.

Of the above-mentioned years, the sidereal lunar year, the synodic lunar year and the *sāvana* year were the most important. The first used to be adjusted to the civil and the sidereal year through intercalation of 9 and 15 days respectively, and the second with the sidereal year through 12 days, for which the *dvādaśāha* period was prescribed. The adjustment of the civil year with the sidereal by intercalating 18 days every third year has already been mentioned in (*e*) above. There are also references to intercalation with 21 days, which Shamasastry explained as a cycle of three *sāvana* years of 360 days each, followed by a year of 381 days. Such a four-year period contains 1,461 days or four times the Julian year of 365¼ days. The *Taittirīya Saṃhitā* refers to a year of 360 days put in order by the sacrifice of five nights, which has been produced as an evidence of knowledge in the *Brāhmaṇa* period of a year of 365 or 365¼ days. But scholars are not unanimous in crediting the Hindus of the *Brāhmaṇa* period with the knowledge of a year of 365 or 365¼ days. A. Berriedale Keith (1) has discussed the matter at length.

Solstices and Equinoxes

Several passages in the *Brāhmaṇas* point unmistakably to the knowledge of solstices among the Vedic Hindus. Consider the following passage of the *Aitareya Brāhmaṇa*:[a]

> 'They perform the *ekaviṃśa* day, the *viṣuvān*, in the middle of the year; by this *ekaviṃśa* day the gods raised up the sun towards the world of heaven (the highest region of the heavens, viz. the zenith). For this reason this sun (as raised up) is (called) *ekaviṃśa*. Of this *ekaviṃśa* sun (or the day), the ten days before are ordained for the hymns to be chanted during the day; the ten days after are also ordained in the same way; in the middle lies the *ekaviṃśa* . . . '.

In the Vedic times year-long sacrifices used to be started from the day following the winter solstice. The *viṣuvān* in the middle of the year was clearly the summer solstice day. The stationary character of the sun at the solstice for 21 days is further to be observed.

More important was the winter solstice day which marked the beginning of the yearly sacrifices and often the beginning of the year and of the *yuga*.

[a] *Ait. Br.*, xviii. 18; *see also* Sengupta (3), p. 156.

A reference to this important day is given in the *Kauṣītakī Brāhmaṇa*[a] as follows:

> 'He (the sun) indeed rests on the new moon day of Māgha, being about to turn towards the north. Thus they rest who are about to perform the rites of the *prāyaṇīya atirātra* (the first day on which *soma* is pressed)... He goes for six months towards the north; they follow him with the ascending celebrations of six days each. He having gone six months towards the north stands still, being about to turn towards the south. Thus they stop, being about to perform the rites of the *Vaiṣuvatīya* day. Thus they reach him for the second time. He goes six months towards the south. They follow him with the returning celebrations of six days each. Having gone six months towards the south he stands still, being about to turn towards the north. Thus they stop, being about to perform the rites of the *Mahāvratīya* day. Thus they reach him for the third time. Because they reach him three times, the year is arranged threefold; for obtaining the year (they do thus). About this there is sung a sacrificial stanza:
>
> 'Arranging the days and nights like a wise spider;
> Six months always towards the south and six months towards the north wanders the sun.'

The year is thus divided into two halves of six months each marked by the winter solstice when the *Mahāvrata* rites are performed and by the summer solstice when the *Viṣuvat* day is observed. Moreover, the winter solstice fell on the new moon of *Māgha*, that is on the new moon preceding the full moon in the *nakṣatra Maghā*. In the circle of asterisms, the new moon of *Māgha* when the sun and the moon are in conjunction clearly falls in the *nakṣatra Dhaniṣṭhā* or *Śraviṣṭhā* (β Delphini). This is also borne out by the well-known statement of the *Vedāṅga Jyotiṣa—prapadyete śraviṣṭhādau sūryācandramasāvudak*—(The sun and the moon turn north at the beginning of the *nakṣatra Dhaniṣṭhā*). When the winter solstice lies in *Dhaniṣṭhā* and the summer solstice in *Maghās* (14 *nakṣatras* ahead), the vernal equinox must lie in the *Kṛttikās*.

Although the equinoxes are not explicitly mentioned in the *Brāhmaṇas*, the coincidence of the vernal equinox with the *Kṛttikās* has been inferred from the fact that this *nakṣatra* was at the head of the asterisms in the time of the *Brāhmaṇas* and from the fact that when the vernal equinox shifted, through precession, to the *nakṣatra Aśvinī*, the latter became the head of the *nakṣatras*. The *Brāhmaṇas* also contain the important statement that the *Kṛttikās* never deviate from the east, which must have been the case when this *nakṣatra* marked the intersection of the ecliptic with the equator.

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[a] *Kauṣ. Br.*, xix. 3; *see also* Thibaut (4), pp. 87–88.

LATE VEDIC AND PRE-SIDDHĀNTIC ASTRONOMY, JAINA ASTRONOMY

In connection with our discussion of astronomical knowledge in the *Saṃhitās* and the *Brāhmaṇas*, we have several times referred to the *sūtras* and the *Vedāṅga Jyotiṣa* because the latter by and large embodied the astronomical knowledge already found in the Vedic period proper. But the late character and composition of the *sūtras* and the *Jyotiṣa* are not in doubt. The *Vedāṅga Jyotiṣa* records the location of the summer and winter solstices in the middle of *Āśleṣā* and beginning of *Dhaniṣṭhā*. From the present positions of the solstices in the asterisms and from the precessional rate of 1° for every 72 years, it is easy to show that at about 1400 B.C. the solstices coincided with the middle of *Āśleṣā* and the beginning of *Dhaniṣṭhā*. This has led many scholars to suggest 1200 B.C. as the time of composition of the *Vedāṅga Jyotiṣa*. But the possibility of an earlier tradition being recorded in the *Jyotiṣa* and other internal and literary evidence strongly suggest it to be a work of the *Sūtra* period, that is after 700 or 600 B.C. (Filliozat placed it between 400 B.C. and A.D. 200). The work is attributed to Lagadha who probably recast it from an earlier work.

THE *VEDĀṄGA JYOTIṢA*

The *Vedāṅga Jyotiṣa*[a] teaches a five-year luni-solar cycle (*yuga*). At the beginning of the cycle, the sun and the moon lie at the starting point of the *nakṣatra Dhaniṣṭhā*. During this period the sun goes round the circle of asterisms 5 times and the moon 67 times. This means that the period has 67 sidereal months and 62 synodic months. Moreover, a solar year has 366 *sāvana* or civil days and the five-year cycle 1,830 *sāvana* days. A synodic month has 30 lunar days or *tithis*, so that a five-year cycle has 1,860 lunar days. These elements give the length of a sidereal month as 27·31 and that of a synodic month as 29·52 *sāvana* days. To summarize these elements, one quinquennial cycle contains

5 sun's revolutions;
67 moon's sidereal revolutions or months;
62 moon's synodic revolutions or months;
1,830 *sāvana* or civil days;
1,835 sidereal days;
1,800 solar days;
1,860 lunar days or *tithis*.

The *Jyotiṣa* divides a *sāvana* day into 30 *muhūrtas*, 1 *muhūrta* into 2 *nāḍikās*, 1 *nāḍikā* into $10\frac{1}{20}$ *kalās*, 1 *kalā* into 124 *kāṣṭhas* and 1 *kāṣṭha* into 5 *akṣaras*. This makes a *sāvana* day equal 603 *kalās* and a lunar day (*tithi*) $593\frac{17}{62}$ *kalās*. The duration of a *nakṣatra* is 610 *kalās*.

[a] *VJ.*, 28–31.

The above elements and the measures have been utilized in calculating the places in the circle of asterisms where the new and the full moon take place during the whole quinquennial cycle. From the explanation given by Thibaut, it appears that each *nakṣatra* space (13° 20′) was further subdivided into 124 parts, and the positions of the new and the full moon were given in terms of the *nakṣatra* and its subdivisions.[a] This is a clear indication of the scientific use of the stellar zodiac for calculating the positions of the sun and the moon.[b]

In the *Jyotiṣa* we also find for the first time the rule for determining the length of the day between the two solstices. The shortest day is given as 12 *muhūrtas* at winter solstice and the longest as 18 *muhūrtas* at summer solstice. In one *ayana* of 183 days, the day length is said to increase or decrease by 6 *muhūrtas*, whence the daily increase or decrease works out to 6/183 or 2/61 *muhūrta*.

SOME ANCIENT ASTRONOMERS OF THIS PERIOD

Varāhamihira, in his *Bṛhatsaṃhitā*, has recorded the names of a large number of astronomers of this period. Some of them are Garga, Parāśara, Kāśyapa, Nārada, Pitāmaha, Sūrya, Puliśa, Vaśiṣṭha, Romaka, Viṣṇugupta, Asita-Devala, Ṛṣiputra, Bhṛgu, Maya, Bādarāyaṇa, Nagnajit and so on. Most of them are mentioned only in name. Passages attributed to some of them are quoted particularly by Varāha's commentator Utpala, but the works of the majority of them are no longer extant. The teachings of Pitāmaha, Sūrya, Puliśa, Vaśiṣṭha and Romaka have been summarized by Varāha in his *Pañcasiddhāntikā* about which we shall speak later. Among the others, the most important are Garga and Parāśara, both of whom compiled *saṃhitās* known after their names. The astronomical knowledge presented in these *saṃhitās* is more or less the same as found in the *Vedāṅga Jyotiṣa*. It is, therefore, no wonder that Somākara, the commentator of the *Jyotiṣa*, quotes extensively from Garga in his exposition of the *Jyotiṣa*.

Garga is also important from the viewpoint of his frequent references to the Greeks (*yavana*), and to the excellence of the astronomical science as studied among their savants. 'The Greeks are indeed *mlecchas*, but amongst them this science (astronomy)', writes Garga, 'is well established; therefore even they are honoured as *Ṛṣis*.' From his references to the fiercely fighting Greeks who penetrated into the heart of Hindusthan (*madhyadeśa*), Kern concluded that Garga lived probably during the period of conquests of the Bactrian Greeks (third to second century B.C.). Parāśara who figures prominently in some of the *Purāṇas* is probably posterior to Garga.

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[a] Thibaut (2), pp. 411–37.

[b] Shamashastry has interpreted such divisions as giving a method of ascertaining readily *parvatithis* and *nakṣatras* (*see* his edition of the *Vedāṅga Jyotiṣa*, Mysore, 1936).

JAINA ASTRONOMY

We have already referred to the Jaina interest in astronomy. *Jyotiṣa* appears quite early in the history of their religious literature and forms an important branch of their study as we know it from the *Bhagavatī-sūtra* and the *Uttarādhyāyana-sūtra*. Śānticandragaṇa, in his preface to his commentary on the *Jambūdvīpaprajñapti*, states that the knowledge of astronomy was an indispensable accomplishment on the part of a Jaina priest who was to decide the right time and place for religious ceremonies. Although the Jainas developed a set of peculiar cosmographical theories which came in for sharp criticism at the hands of Brāhmaṇa astronomers, they adopted and followed, with minor variations, the Brāhmaṇic astronomy of the *Vedāṅga Jyotiṣa*.

The principal source of Jaina astronomy is *Sūryaprajñapti*, a work divided into 20 books and written in *ardhamāgadhī prākṛt*, which is extant with an elaborate commentary by Malayagiri. Free from Greek influence, the work was probably written a few centuries before the Christian era. Its authorship has been attributed to Mahāvīra. The next important astronomer was Bhadrabāhu (d. 298 B.C.), a *śrutakevalin* and a prominent personage in the history of Jaina religion. He is believed to be the author of a commentary on the *Sūryaprajñapti* and of an astronomical *saṃhitā* known after his name, of which only fragments have been preserved in later commentaries. Then we have the *Jambūdvīpaprajñapti* with a number of commentaries, of much later date, where elaborate descriptions of the different *dvīpas* of the Jaina cosmography are met with.

The peculiarity of the Jaina astronomy consists in its conception of two suns, two moons and two sets of 27 *nakṣatras*. This conception is a consequence of the Jaina cosmography according to which the earth is regarded as a series of flat concentric rings of land masses separated by concentric ocean rings. The central circle *Jambūdvīpa*, with the mountain *Sudarśa Meru* in the centre, is encircled by the salt ocean. Beyond it lies the *Dhātukī Dvīpa* encircled by the black ocean *Kālodadhi* and beyond that the *Puṣkara Dvīpa* rimmed by an impassable mountain range, the *Mānuṣottara Parvata*. The innermost *Jambūdvīpa* is divided into four quarters, of which the southernmost part is *Bhāratavarṣa* (India). The sun, the moon and the stars are assumed to move in circles, parallel to the earth's surface, round Mount Meru as centre. As *Jambūdvīpa* is divided into four quarters and four directions, and as the sun should make day in succession to the regions south, west, north and east of Meru, the sun's diurnal orbit is also divided into four quarters. Since the length of a day, disregarding variations, is 12 hours or 15 *muhūrtas*, the same sun after making day over *Bhāratavarṣa* in the southern quarter cannot reappear on the following morning as it still has three quarters to travel. To obviate this difficulty, the theory supposes two similar suns, *Bhārata* and *Airāvata*, separated from each other by half the orbit, to describe the whole orbit. In this process each sun makes day over *Bhāratavarṣa* on alternate days.

This is given in the *Sūryaprajñapti* with Malayagiri's commentary as follows:[a]

> 'There are two suns, Bhārata and Airāvata. They both move through half a diurnal circle in the course of 30 *muhūrtas*; i.e. in the course of 60 *muhūrtas* or 2 days, they complete a full diurnal circle. That sun which moves in the outermost circle in the southern hemisphere is called Bhārata, because it illumines the Bhāratakhaṇḍa. The other which moves through the same outer circle in the northern hemisphere is called Airāvata, because it illuminates the Airāvata area.'

To explain the variations of day length, 183 diurnal circles are imagined. Each sun after rising in the first circle rises in the next circle each following morning, increasing the day-length in the *uttarāyaṇa* and decreasing it in the *dakṣiṇāyana* by 6 *muhūrtas*, as taught in the *Vedāṅga Jyotiṣa*.

For calendrical purposes, the *Sūryaprajñapti* adopts the five-year cycle beginning with the summer solstice when the full moon takes place at the *nakṣatra Abhijit*. Such a five-year cycle or *yuga* has 1,830 *sāvana* days, 1,800 'solar' days, 1,860 *tithis*, 60 solar months, 61 *sāvana* months, 62 synodic months and 67 sidereal months. Thus a year consists of 366 *sāvana* days. The year having 360 solar days is called a *ṛtu* year. The calendar also recognizes a lunar year of $354\frac{12}{62}$ days and a *nakṣatra* year of $327\frac{51}{67}$ days, giving the lengths of a synodic and a sidereal month as $29\frac{32}{62}$ and $27\frac{21}{67}$ days respectively. The year is divided into 2 *ayanas* of 183 days each.

The ecliptic is divided into 28 unequal spaces, beginning with the *nakṣatra Abhijit*. The scale conforms to the sidereal month-length and the circle is divided into $27\frac{21}{67}$ parts. The *Sūryaprajñapti* contains the statement that the planets travel faster than the sun and the stars, the sun slower than the moon and the stars faster than the *nakṣatras*. Regarding the apparently awkward last statement, Kaye thinks that the motion of the stars with regard to the fixed *nakṣatras* which are here used as a sort of zodiacal scale of reference probably means their precession with respect to equinoxes.[b]

THE PERIOD OF THE COMPOSITION OF THE ASTRONOMICAL *SIDDHĀNTAS*—THE FIVE *SIDDHĀNTAS*, THE *SŪRYA-SIDDHĀNTA*, THE ASTRONOMICAL WORKS AND COMMENTARIES OF THE PERIOD

The first few centuries of the Christian era are very important in the history of Hindu astronomy. The inaccuracies and the insufficiency of the Vedic and the Sūtraic astronomy must have been felt for a long time. The crude calendrical astronomy based on uncorrected motions of the sun and the moon against a stellar zodiac had outlived its function and utility.

[a] Das, pp. 30–42.

[b] Kaye (2), p. 21.

Accurate study of heavenly bodies, in which the planets were gradually to be incorporated, involved the application of more sophisticated mathematics, adoption of a system of co-ordinates, and more reliable determination of their periods of revolution, the sizes of the earth, the relative sizes of the sun and the moon, and so on. Although interest in the eclipse phenomena had been very ancient and recorded at several places in the earliest *Saṃhitās* and the *Brāhmaṇas*, their calculations and predictions were beyond the scope of the kind of astronomy so far practised and taught. All this must have occupied the serious attention of the astronomers of this period, for by about A.D. 400 or even earlier we for the first time come across an altogether new class of astronomical works called *siddhāntas* dealing with matters and methods unknown in the works of any previous period. This new class of works is characterized, among others, by the replacement of the *nakṣatra* system by the 12 signs of the zodiac, the correct length of the year, the correct rules for calculating day-lengths and oblique ascensions, the determination of mean longitudes by the *ahargaṇa* method, the study of planetary motions by reference to a celestial sphere, the system of great and small circles and the geometric models of eccentric circles and epicycles, the ideas of parallax and its calculation, and the calculation of solar and lunar eclipses. The emphasis on computations also opened the way to new methods of analysis. Integral solutions of indeterminate equations, rudiments of plane and spherical trigonometry, besides common geometrical, arithmetical and algebraic practices, became integral parts of the new science. Increasing mathematization very soon necessitated the incorporation of a few chapters on mathematics into most treatises on astronomy, and the practice was carried to such an extent that astronomy and mathematics became inseparable for several centuries to come.

THE FIVE *SIDDHĀNTAS*

The word *siddhānta* means 'final conclusion' or 'solution'. Its application to the reformed astronomical texts of the period, seeking to present the correct solutions of astronomical problems, was no doubt quite appropriate. Tradition says that there were 18 original *siddhāntas*, as Sudhākara Dvivedi, in his *Gaṇakataraṅgiṇī*, mentions; these 18 *siddhāntas* were by Sūrya, Pitāmaha, Vyāsa, Vaśiṣṭha, Atri, Parāśara, Kāśyapa, Nārada, Garga, Marīci, Manu, Aṅgirā, Lomaśa (Romaka), Pauliśa, Cyavana, Yavana, Bhṛgu and Śaunaka. Most of them are lost and several of them which invoked the name of some ancient sage to gain popularity cannot certainly claim to belong to this class of astronomy. Of the above list, the *Sūrya-siddhānta*, both in its old version as summarized by Varāhamihira and its later improved form through revisions by several authors, has come down to us. We are also indebted to Varāhamihira for preserving for us the main features of four others, namely the *Paitāmaha*, the *Vaśiṣṭha*, the *Pauliśa* and the *Romaka*. The teachings of the five *siddhāntas* as summarized by Varāha in his *Pañcasiddhāntikā* will now be briefly discussed.

The Paitāmaha-siddhānta

This is the most inaccurate of the five *siddhāntas* noticed. Its astronomical elements are the same as those of the *Vedāṅga Jyotiṣa.* Thus it teaches a quinquennial cycle containing 5 revolutions of the sun, 67 revolutions of the moon, 60 solar months, 62 synodic months, 2 intercalary months, 1,830 *sāvana* days and 1,860 *tithis.* The cycle begins with the conjunction of the sun and the moon at the first point of the *nakṣatra Dhaniṣṭhā.* The rule for the shortest and the longest day is the same as that given in the *Vedāṅga Jyotiṣa.*

The Vaśiṣṭha-siddhānta

Although rated inaccurate in the case of its *tithis* compared to the *Pauliśa*, the *Romaka* and the *Sūrya-siddhānta*, the teachings of the *Vaśiṣṭha-siddhānta* were more advanced than those of the *Paitāmaha.* In this system, the traditional *nakṣatras* were supplemented with a zodiac with its subdivisions of signs, degrees and minutes for the first time. Lagna, that is the ecliptic point on the eastern horizon, is mentioned and rough rules for finding it from the shadow and vice versa are given. We also find rules for determining day-lengths. Rough rules for calculating mean longitudes from the length of the midday shadow are given. This *siddhānta* reveals knowledge of the anomalistic month and gives its values as $\frac{248}{9}$ and $\frac{3031}{110}$. More importantly, the *Vaśiṣṭha-siddhānta* also deals with the true motions of the five planets, Venus, Jupiter, Saturn, Mars and Mercury, and recognizes their motions as direct, stationary (*anuvakra*), retrograde (*vakra*) and again direct. The synodic periods in days of these planets are given as follows:

Venus	..	$584\frac{1}{11}$ days
Jupiter	..	$399\frac{1}{9}$ days
Saturn	..	$378\frac{1}{11}$ days
Mars	..	$780\frac{2}{45}$ days
Mercury	..	115 days 52 *nāḍikās* 45 *vināḍikās*

The *siddhānta* also gives the equivalence between synodic and sidereal revolutions for each planet, from which the sun's sidereal revolutions in a given number of days, or in other words the length of the solar year, can be easily calculated. For Jupiter, the text gives 36 sidereal revolutions as equivalent to 391 synodic revolutions. This means that the sun executes 427 sidereal revolutions during the same time as the Jupiter makes 391 synodic revolutions, that is in the course of 391×399 days (omitting $\frac{1}{9}$ day). The length of the solar year, according to the *Vaśiṣṭha-siddhānta*, works out to 365·36 days approximately, a considerable improvement upon the value adopted in the *Vedāṅga Jyotiṣa.* At another place,[a] the *siddhānta* specifically gives the sidereal year length as $365\frac{1}{4}$ days, as has been shown

[a] *Psi.*, ii. 1.

by T. S. Kuppanna Sastry. The *Vaśiṣṭha-siddhānta* was recast by Viṣṇu-candra whose name is mentioned by Brahmagupta and al-Bīrūnī.

The Pauliśa-siddhānta

Varāha states that 'the *siddhānta* made by Pauliśa is accurate'. The elements of this *siddhānta* are presented in chapters 3 to 7 and partly in chapter 1. These elements include calculation of *ahargaṇa*, that is the number of civil days elapsed from a certain epoch up to a given date, the determination from the *ahargaṇa* of the mean places of the sun and the moon and thence their true places. The rules for finding the longitude of the moon are analogous to the *vākyam* method found later on in the Tamil astronomy. This *siddhānta* also contains miscellaneous rules for finding direction, place and time, sine tables and simple calculations of eclipses. From a statement that there are 43,831 civil days in 120 years, the length of the year works out to 365·2583 days.

The *Pauliśa-siddhānta*, in giving the quantities to be added to or subtracted from the mean sun in order to obtain the true places, reveals knowledge of the anomaly (*kendra*) and the equations of the centre. According to Thibaut's interpretation, the rules indicate that for anomalies 10°, 40°, 70°, 100°, 130° and 160° the corresponding equations should be 21′, 96′, 139′, 140′, 108′ and 50′. But how the equations are obtained is not mentioned; that is there is no hint as to any epicyclic or eccentric model upon which to calculate them.[a]

The sine table given in chapter 4 may be due to Pauliśa or may be a common feature of all the three accurate *siddhāntas*. The radius adopted for calculating the table is 120′ and not 3438′ used in later astronomical texts. There is also evidence of the beginnings of spherical trigonometry in the *siddhānta*. The formula given for the variation of day-length takes the form:

$$R \sin (\text{ascensional difference}) = R \tan \phi \tan \delta$$

where ϕ = latitude and δ = the sun's declination.

Pauliśa's calculations of lunar and solar eclipses are rough and less accurate than those given in the *Romaka*- and the *Sūrya-siddhānta*. The sidereal period of the revolution of the moon's nodes is given as 6794·6854, the semi-diameter of the moon as 17′ and that of the sun as 16·8′. The moon's greatest latitude is given as 270′ (4° 30′). The parallax in longitude is expressed in time, that is by the difference in time between the instant of the new moon and the instant of conjunction as it appears to the observer. The expression is given by

$$\text{Parallax} = \frac{4\ R \sin (\text{sun's hour angle})}{R}\ \textit{nāḍikās}\ (1\ \textit{nāḍikā} = \tfrac{1}{60}\ \text{day}).$$

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[a] In a private communication to the author, Sri T. S. Kuppanna Sastry has suggested that the method is possibly the same as that of the *Vākyakaraṇa*.

Al-Bīrūnī, who derived his information on Hindu astronomy both from this *siddhānta* as summarized by Varāha as also from Brahmagupta's *Brāhmasphuṭa-siddhānta*, expressed the view that its author Pauliśa was a Greek from the city of Saintra which he supposed to be Alexandria.[a] Besides Varāha's summary of the *Pauliśa-siddhānta*, references to, and elements from, a *Pauliśa-siddhānta* were given by Bhaṭṭotpala and Pṛthūdakasvāmin. These elements differ from Varāha's Pauliśa and agree more closely with those found in the *Saura* of the *Pañcasiddhāntikā* and in Āryabhaṭa's *ārdharātrika* system. Possibly the original work known to Varāhamihira underwent one or several emendations with the passage of time.

The Romaka-siddhānta

The elements of the *Romaka-siddhānta* are summarized partly in chapter 1 where matters concerning *yuga*, *ahargaṇa*, intercalation of lunar months and such general topics are discussed and in chapter 8 dealing with eclipse calculations. The title suggests its foreign origin which is further supported by its astronomical elements and the year being tropical. It introduces a luni-solar cycle of 2,850 years containing 1,050 intercalary months and 16,547 omitted lunar days. The total number of synodic months in this period will be $2{,}850 \times 12 + 1{,}050$ or 35,250; the total number of civil days will be $35{,}250 \times 30 - 16{,}547$ or 1,040,953. The lengths of the year and the synodic month calculated from these elements compare favourably with those given by Hipparchus and Ptolemy as follows:

	Romaka-siddhānta	*Hipparchus-Ptolemy*
Year ..	365 days 5 h 55′ 12″	365 days 5 h 55′ 15·8″
Synodic month ..	29 days 12 h 44′ 2·2″	29 days 12 h 44′ 2·5″

The anomalistic month is given as 3031/110 days or 27·554 days. This makes the moon's daily motion in anomaly as $13^\circ\ 3'\ 53''\ 58^{III}\ 55^{IV}\ 51^{V}\ 45^{VI}$ in close agreement with Ptolemy's $13^\circ\ 3'\ 53''\ 56^{III}\ 29^{IV}\ 38^{V}\ 38^{VI}$ in sexagesimal units.

It is to be noted that the total number of years and synodic months in the luni-solar cycle used in the *Romaka-siddhānta* are both divisible by 150. The result of this reduction is that 19 solar years comprise 235 synodic months. This is the well-known 19-year cycle of Meton, the Athenian astronomer (432 B.C.). The reason for multiplying Meton's cycle by a factor of 150 was probably to arrive at a *yuga* containing a whole number of civil days in conformity with the established Hindu practice.

The information given in the *Romaka-siddhānta* regarding the equations of centre for the sun and the moon is more detailed, but again without any indication as to how these corrections were obtained. In finding the anomaly, that is the difference between the longitude of the mean

[a] Sachau, I., p. 153.

sun and that of the apogee, the longitude of the apogee is stated as 75° as against Ptolemy's value of 65° 30′. The following equations of centre of the sun and the moon for their anomalies at intervals of 15° are given (Table 2.2).

TABLE 2.2

The equations of centre of the sun and the moon in the Romaka-siddhānta

Anomaly	15°	30°	45°	60°	75°	90°
Romaka						
Equation of centre						
Sun ..	34′ 42″	1° 8′ 37″	1° 38′ 39″	2° 2′ 49″	2° 17′ 5″	2° 23′ 23″
Moon .	1° 14′	2° 25′	3° 27′	4° 15′	4° 44′	4° 55′
Ptolemy						
Equation of centre						
Sun .		1° 9′		2° 1′		2° 23′
Moon .						5° 1′

For purposes of comparison, a few values given by Ptolemy are quoted. The equations for the sun agree very closely, but this is not so for those for the moon. The text gives latitudes of the moon, parallaxes in longitudes and latitudes and a few other details.

At one time Śrīsena appeared to be the author of the original *Romaka-siddhānta*. Brahmagupta himself, in his *Brāhmasphuṭa-siddhānta*, refers to Śrīsena as the author of the work. From a more careful study of the passage, Thibaut showed that Śrīsena was at best a poor compiler who possibly worked on the original *Romaka-siddhānta* and incorporated into it planetary elements from other authorities, namely Lāṭa, Vijayanandin and Āryabhaṭa I. In fact, Brahmagupta also severely criticized Śrīsena's effort and passed the remark that he had turned a heap of jewels, which the original *Romaka-siddhānta* was, into a patched rag. In this connection, the name of Lāṭa is important, for Varāha himself referred to Lāṭa as a commentator of the *Romaka-siddhānta* and Brahmagupta held him in respect.

The Sūrya-siddhānta

The Sūrya-siddhānta, also called the *Saura-siddhānta*, was according to Varāhamihira the most accurate of the five *siddhāntas*. The main features of this work summarized in the *Pañcasiddhāntikā* appear in chapters 9-11, 16 and 17; the *yuga* elements of the sun and the moon are given in chapter I. 14; chapters 13 to 15 discuss some of its general matters, e.g. cosmogony, geography, etc. In the history of Hindu astronomy, the *Sūrya-siddhānta* occupies a very important position in that it does not appear to be the work of a single individual, but underwent periodic revisions and served as a standard astronomical text in different periods of

time. Thibaut called Varāha's summary the old version of the *siddhānta* to distinguish it from the modern version we now possess. P. C. Sengupta has shown that there was certainly an old *Sūrya-siddhānta* dated about A.D. 400, which was brought up to date by Varāha himself on the basis of Āryabhaṭa's *ārdharātrika* (midnight) system; and that the modern *Sūrya-siddhānta*, with additions of improved data from Brahmagupta and others, continued to develop till the twelfth century A.D. or even later.

Coming to Varāha's version, the *siddhānta* taught that 180,000 years contained 66,389 intercalary months and 1,045,095 omitted lunar days. This gives 65,746,575 days in the *yuga* thus conceived. For the sake of comparison with the elements given in the modern *Sūrya-siddhānta*, the period of 180,000 years can be converted to a *mahāyuga* of 4,320,000 years by multiplying the former by 24 and the total number of days in such a period worked out. The mean motions of planets are given in chapter 16. The integral numbers of revolutions performed by the planets in a *mahāyuga* can be easily calculated, and they are set down in Table 2.3. The values

TABLE 2.3
Planetary revolutions in a Mahāyuga

Planet	*Sūrya-siddhānta* (Summarized by Varāha)	Āryabhaṭa I (*Ārdharātrika* system reproduced in Brahmagupta's *Khaṇḍakhādyaka* and in Bhāskara I's *Mahābhāskarīya*)	Modern *Sūrya-siddhānta*
Sun ..	4,320,000	4,320,000	4,320,000
Moon .	57,753,336	57,753,336	57,753,336
Mars . .	2,296,824	2,296,824	2,296,832
Jupiter . .	364,220	364,220	364,220
Saturn . .	146,564	146,564	146,568
Mercury	17,937,000	17,937,000	17,937,060
Venus . . .	7,022,388	7,022,388	7,022,376
Moon's apogee ..	488,219	488,219	488,203
Moon's node ..	232,226	232,226	232,238
Number of civil days in a *mahāyuga* ..	1,577,917,800	1,577,917,800	1,577,917,828

given in the modern *Sūrya-siddhānta* and in the *ārdharātrika* system of Āryabhaṭa are also shown in the table for the sake of comparison.

It will be seen that the planetary revolution numbers in a *mahāyuga*, as given in the *ārdharātrika* system of Āryabhaṭa I and in the old *Sūrya-siddhānta* summarized by Varāha, are the same, but these elements and other astronomical constants differ in several cases from those of the modern *Sūrya-siddhānta*. This identity of astronomical elements in the old *Sūrya-siddhānta* with those of Āryabhaṭa's *ārdharātrika* system has given rise to the view that the former might have been recast by Varāha after the teachings of his older contemporary Āryabhaṭa I.

Mahāyuga

The concept of *mahāyuga* is the central feature of the Indian astronomical *siddhāntas.* It developed from the idea of *yuga* or cycle which is very old indeed and is met with in the *Brāhmaṇa* literature. It is a period at the beginning of which all planetary bodies are in conjunction, during which they all perform integral numbers of revolutions, and at the end of which, therefore, they are again in conjunction. In selecting the length of such a cycle, care was taken that the apsides and the nodes also have whole numbers of revolutions. The *mahāyuga* of 4,320,000 years is such a period. Biot demonstrated that the length of the year as 365 days 6 h 12′ 35·56″ is such that the least number of years containing a whole number of civil days is 1,080,000. The *mahāyuga* also called the *caturyuga* is just 4 times this number. The number 108 is again 4 times 27, the number of *nakṣatras.*

According to Āryabhaṭa I, a *mahāyuga* (simply called a *yuga*) is divided into four equal parts or *yugapādas*, each consisting of 1,080,000 years. In the modern *Sūrya-siddhānta*, a *mahāyuga* is subdivided into four mundane ages, e.g. the *Kṛta* or Golden Age, the *Tretā* or Silver Age, the *Dvāpara* or the Brazen Age and the *Kali* or the Iron Age.[a] The durations of these ages are in the descending order of 4, 3, 2 and 1 and have the following solar years:

The *Kṛta*	..	1,728,000 solar years
The *Tretā*	..	1,296,000 ,,
The *Dvāpara*	..	864,000 ,,
The *Kali*	..	432,000 ,,

These divisions are in keeping with the traditions of the *Smṛti* and the *Purāṇas*. Their use in an astronomical *siddhānta* is met with for the first time in the works of Brahmagupta, from which it might have been incorporated in the modern *Sūrya-siddhānta* by its unknown redactor. A special importance attaches to the *Kali* or the current Iron Age through which we are at present passing. At the commencement of this epoch, the planets are assumed to be in conjunction for the last time at the initial point of the Hindu sphere. As all astronomical data and calculations given in the *Sūrya-siddhānta* and works following more or less the same system depend on this assumption, it is important to know its date. This epoch started at midnight at the meridian of Ujjayinī between February 17 and 18, 3102 B.C.

Revolutions of the apogees of the sun and the planets are not recognized in Varāha's version of the *Sūrya-siddhānta* although it is a characteristic feature of the modern *Sūrya-siddhānta* and other later astronomical texts. The *ahargaṇa* method of finding the mean longitudes of the sun, the moon and the planets is the same as that found in the modern version.

[a] Fleet, pp. 479–96.

The old *Sūrya-siddhānta*, like the modern, makes use of an epicyclic model for calculating the true planetary positions. This and other geometric models as used by the Hindus will be explained in what follows. For such calculations, the important elements are the longitudes of the apogees and the dimensions of epicycles for the *manda* (equation of centre) and the *śīghra* (equation of conjunction) corrections. Table 2.4 gives these elements in the old and the modern *Sūrya-siddhānta*.

TABLE 2.4

Longitudes of apogees and dimensions of manda and śīghra epicycles in Varāha's Sū. Si. and the modern Sū. Si.

	Longitude of apogee		*Manda* epicycle			*Śīghra* epicycle		
	Sū. Si. (Varāha)	Modern *Sū. Si.*	*Sū. Si.* (Varāha)	Modern *Sū. Si.* (odd)	(even)	*Sū. Si* (Varāha)	Modern *Sū. Si.* (odd)	(even)
Sun ..	80°	77° 14′	14°	13° 40′	14°	–	–	–
Moon ..			31°	31° 40′	32°	–	–	–
Mars ..	110°	130°	70°	72°	75°	234°	232°	235°
Jupiter ..	160°	171° 16′	32°	32°	33°	72°	72°	70°
Saturn ..	240°	236° 37′	60°	48°	49°	40°	40°	39°
Mercury ..	220°	220° 36′	28°	28°	30°	132°	132°	133°
Venus ..	80°	79° 49′	14°	11°	12°	260°	260°	262°

The difference in the values of the above elements clearly points to the modifications introduced into this standard text since the days of Varāhamihira. In the old *Sūrya-siddhānta*, the dimensions of the epicycles were assumed to remain constant over odd and even quadrants; in the modern version, presumably following Āryabhaṭa I and others, epicycles have been made to vary between odd and even quadrants. The formula for determining the *manda* correction, i.e. the equation of centre, is given by[a]

$$\sin \mu = \frac{\sin \alpha \,.\, 2\pi e}{2\pi R} = \frac{\sin \alpha \,.\, \odot_\mu}{360}$$

where μ = the equation of centre; e = eccentricity or radius of the *manda* epicycle; R = radius of the deferent circle (the Hindu radius); $\odot_\mu$ = circumference of the *manda* epicycle. This formula is the same as that given in the modern *Sūrya-siddhānta*.

Rules for finding the *śīghra* correction for planets are given in chapter 17, 4–6. If γ be the argument, that is the angle between the mean planet and the sun, r the radius of the *śīghra* epicycle, and R the radius (*trijyā*) of the deferent circle, the correction σ is given by

[a] *P.Si.*, ix. 7-8.

$$R \sin \sigma = \frac{R \cdot r \sin \gamma}{\sqrt{(r \sin \gamma)^2 + (R + r \cos \gamma)^2}}.$$

These rules, in their essential features, are in agreement with those found in the modern *Sūrya-siddhānta*. P. C. Sengupta attempted to show that Varāha, in preparing his version of the old *Sūrya-siddhānta*, borrowed the epicyclic method of calculating the equations of centre and argument from Āryabhaṭa I.[a]

The old *Sūrya-siddhānta* gives rules for calculations of the solar and lunar eclipses which have been carried forward in the modern version with further details.

The old *Sūrya-siddhānta*, even after its modernization after the works of Āryabhaṭa I and Brahmagupta, continued to be in use in different parts of the country. In the beginning of the ninth century, the Nepalese astronomer Sumati wrote a *karaṇa*, whose elements were based on the old *Sūrya-siddhānta*. Śatānanda's calendrical work *Bhāsvatī* (eleventh century A.D.) also utilized this work to a great extent.[b]

The Modern Sūrya-siddhānta

It would have perhaps been proper to deal with the modern *Sūrya-siddhānta* later on after noticing the works of Āryabhaṭa I, Bhāskara I, Brahmagupta, Mañjulācārya and others inasmuch as the form in which we now have it developed out of the efforts of these distinguished astronomers. But, after having started with the old version and made frequent references to some of the elements in which it differed from the modern, a few remarks about the modern version here would appear more preferable. To emphasize its high antiquity, the text opens with the statement that the knowledge of astronomy presented therein was revealed to an *asura* called Maya by the sun god himself. The mention of Maya at one time led to much speculation. Observing that the name of the Egyptian king, Ptolemaios, appeared as *Turamaya* in Indian inscriptions, Weber conjectured that *asura* Maya might be the altered name of the celebrated Greek astronomer Ptolemy himself. Such conjectures are no longer held seriously even in the background of unmistakable influence of Greek astronomy (possibly pre-Ptolemaic) on Hindu astronomy of the *siddhāntic* period. According to al-Bīrūnī, the *Sūrya-siddhānta* was composed by Lāṭa, a contemporary of Āryabhaṭa I. Possibly Lāṭa composed a commentary on it.

The work is divided into 14 chapters, e.g. (i) Mean motions of the planets (*madhyamādhikāra*), (ii) True places of the planets (*spaṣṭādhikāra*), (iii) Determination of direction, place and time (*tripraśnādhikāra*), (iv) Lunar eclipse (*candragrahaṇādhikāra*), (v) Solar eclipse (*sūryagrahaṇādhikāra*), parallax, (vi) Projection of eclipses (*chedyakādhikāra*), (vii) Planetary

[a] Sengupta, Introduction to Burgess' translation of the *Sūrya-siddhānta*.
[b] Shukla, Introduction to the *Sūrya-siddhānta*.

conjunctions (*grahayutyadhikāra*), (viii) Conjunction of planets with junction-stars of *nakṣatras* (*nakṣatragrahayutyadhikāra*), (ix) Heliacal risings and settings of planets (*udayāstādhikāra*), (x) Moon's risings and settings and the elevation of the moon's horns (*śṛṅgonnatyadhikāra*), (xi) Phenomena called *pāta* (*pātādhikāra*), (xii) Cosmogony and geography (*bhūgolādhyāya*), (xiii) Astronomical instruments (*jyotiṣopaniṣadadhyāya*) and (xiv) Reckoning of time (*mānādhyāya*). The text is highly condensed and written in a manner which gives the impression that its main purpose was not to teach and explain the principles of astronomy, but to provide a set of rules for memorization. In this the *Sūrya-siddhānta* was no exception as most Hindu astronomical texts were really compendiums of astronomical rules, the task of exposition being left to the teachers and the commentators. As to brevity and condensation, the work covered the subject in 500 verses whereas the *Brāhmasphuṭa-siddhānta* needed 1,008 verses, Śrīpati's *Siddhānta-śekhara* 890 verses and Bhāskara II's *Siddhānta-śiromaṇi* 962 verses. Even then the text is far less cryptic and condensed than the *Āryabhaṭīya* which attempted to present its system in 120 verses, including the 33 stanzas on mathematics and the 10 *gīti* stanzas.

The *mahāyuga* system and the theories of planetary motions have already been referred to in our discussion of the old *Sūrya-siddhānta*. Regarding planetary motions, the modern version, interestingly enough, contains an account which appears to have been developed before the epicyclic theory found general acceptance. According to this, the planets are attached, by cords of air, to invisible beings called forms of time which are stationed at the *uccas* (*mandocca* and *śīghrocca*) and the *pātas* (nodes). The planets are impelled in their motions by the provector wind (*pravāhavāta*) uniformly, but the invisible gods at the *uccas* pull or push them in such a way that their motions appear variable.

Special mention should be made of the treatment of the precession of equinoxes, which is missing from its earlier version. The precessional rate and the rules of correcting the longitudes by taking account of it are given in chapter 3, verses 9–12. From the fact that these rules do not appear in their proper context either in chapter I or II where methods of finding mean and true planetary motions are discussed, but are surreptitiously introduced where these are least expected, Burgess concluded that these were interpolations found necessary as a result of afterthought.[a] As we shall see later, two theories regarding precessional motion were propounded by different schools of Hindu astronomers. The first and the more ancient view is the theory of libration or oscillation of the equinoxes about a fixed point. In this theory the equinoxes, like the swing of a pendulum, at first move eastward, reach the maximum amplitude and then move westward. The number of oscillations executed in a *mahāyuga* is given as 600 making the time period 7,200 years. The maximum eastward or westward deviations from the fixed point are set

[a] *See* Burgess' notes to his translation of *Sū-Si.*, iii. 9–12.

down differently by different authorities, accounting for differences in the annual precessional rates. The *Sūrya-siddhānta* has adopted this libration theory and given the maximum eastward or westward deviation as 27° whence the annual precessional rate works out to 54″ as against the modern value of 50·25″. A similar libration theory is met with in the *Soma-*, *Śākalya-* and *Laghu Vāśiṣṭha-siddhānta*. The other theory is that of a complete revolution of the equinoxes through the circle of asterisms, propounded for the first time in India by Mañjulācārya (A.D. 932) and clearly explained by Bhāskara II. Mañjula states that the equinoxes revolve 199,669 times in a *kalpa* (that is 1,000 *mahāyugas*), whence the period of one revolution works out to 21,635·8073 years and the annual precessional rate 59·9″.

The *Sūrya-siddhānta* in its modern form enjoyed great popularity for several centuries. This is attested by a large number of commentaries written by able astronomers and by the richness of the manuscript materials available in the libraries of India and abroad.[a] Some of the commentators include Bhaṭṭotpala (A.D. 966), Caṇḍeśvara and Mallikārjuna Sūri (both twelfth century A.D.), Parameśvara (A.D. 1432), Yallaya (A.D. 1472), Bhūdhara (A.D. 1572), Nṛsiṃha Daivajña (A.D. 1586), Raṅganātha (A.D. 1603), Kamalākara (A.D. 1618), Viśvanātha (A.D. 1628) and Dādābhāi (A.D. 1719). Besides these, there exist several anonymous commentaries as well as astronomical tracts based on the rules of this great *siddhānta*.

LEADING ASTRONOMERS OF THE PERIOD

Āryabhaṭa I (*b.* A.D. 476)

The importance of Āryabhaṭa lies in the fact that he probably was in the vanguard of the new astronomical movement which resulted in the recasting of this new branch of knowledge about the fifth century A.D. Piecemeal efforts might have started earlier as is evident from Varāhamihira's account of the five *siddhāntas*, and before and about the time when Āryabhaṭa flourished there were certainly astronomers of repute who were variously engaged in reforming astronomy, but little is known about their contributions as their works have not survived. As matters stand, the *Āryabhaṭīya* is the earliest preserved astronomical text bearing the name of an individual of the scientific period of Indian astronomy. Moreover, his place at the head of this movement is assured by the great influence his works and teachings wielded among astronomers of subsequent ages, and by the existence of a long line of followers who propagated his views through excellent commentaries.

From his *Āryabhaṭīya*,[b] we learn that he was 23 years of age in A.D. 499 when he wrote his famous work, which gives A.D. 476 as the year of his birth. From another statement of his[c] that he sets forth in his work the science which is held in high esteem at Kusumapura (a place near modern

[a] Sen (5), pp. 217–19. [b] *Ā. Kāla.*, 10. [c] *Ā. Gaṇita.*, 1.

Patna), scholars have thought for a long time that Āryabhaṭa was either born in Kusumapura or lived and taught in that great city of ancient India. Such a view now appears untenable in the light of recent studies on the works of Bhāskara I and his commentators and also of the medieval commentators of Āryabhaṭa. In these works, Āryabhaṭa is frequently referred to as an *āśmaka*, that is one belonging to the Aśmaka country which is the name of a country in the south, possibly Kerala. His work is sometimes designated as *Āśmaka-sphuṭa-tantra*. These findings coupled with the fact that commentaries of, and works based on, *Ārya-bhaṭīya* have come largely from South India, from Kerala in particular, certainly constitute a strong argument in favour of Kerala being the main place of his life and activity.

Āryabhaṭa's mathematical-astronomical masterpiece, the *Āryabhaṭīya*, is composed in four sections, e.g. *Gītikāpāda*, *Gaṇitapāda*, *Kālakriyāpāda* and *Golapāda*. Of these the *Gaṇitapāda* deals exclusively with mathematics and the *Daśagītikā* deals, among others, with an alphabetical system of expressing numbers, which will be considered under mathematics in a separate chapter. The astronomical elements and parameters are given in the *Daśagītikā* in his novel alphabetical system. The two remaining sections, the *Kālakriyā* and the *Gola*, deal with astronomical principles and methods of computation in a highly condensed form. *Kālakriyā* means the reckoning of time, and as such we find in this section a discussion of such topics as the division of time and the circle, definitions of solar year, lunar month, civil day, sidereal day, intercalary months, omitted lunar days, planetary orders and movements, the eccentric-epicyclic models, use of these models for the calculations of true planetary positions, calculation of true distances of planets from the earth and related matters. Thus this section deals more or less with such topics as we find discussed under chapters called *madhyamādhikāra* and *spaṣṭādhikāra* of later astronomical texts. Āryabhaṭa does not give methods for the *ahargaṇa* for calculating the mean longitudes of planets, the knowledge of which he possibly took for granted. His treatment of the eccentric-epicyclic model is important, for it appears possible that Varāhamihira might have adopted it in recasting the older *Sūrya-siddhānta* in the form given in his *Pañcasiddhāntikā*. In this model, Āryabhaṭa used the hypotenuse in calculating the equation of the centre as also for the conjunction correction. This was followed up by astronomers of his school. But Brahmagupta and others used the hypotenuse for the conjunction correction and the radius as an approximation for calculating the equation of the centre.

The last section *Gola* means the sphere. Here the methods of representing planetary motions in a celestial sphere are explained and such terms as prime vertical, meridian, horizon, hour circle, equator, ecliptic, etc., are defined. The sun, the nodes of the moon and planets and the earth's shadow move along the ecliptic which is inclined to the equator at an angle of 24°. The rotation of the earth about its axis is given as an explanation for the apparent westward motion of the stationary asterisms, through

the well-known simile of a man in a moving boat, to whom a fixed object appears to move in the opposite direction. Āryabhaṭa was the first among the Indian astronomers to have mentioned the rotation of the earth to explain the apparent daily motions of the fixed stars, although he was in this opposed and even bitterly criticized by later astronomers. His followers, however, explained the verse in the usual sense. The diurnal rotation of the earth was known to the Greeks several centuries earlier, for in the fourth century B.C. Heraclides of Pontus and his contemporary Ecphantus had clearly held this view. Other topics discussed in the *Gola* include parallax, the eclipses and related matters. Thus in the *Gola* are compressed a set of rules which usually find their treatment in chapters called *tripraśnādhikāra*, *candragrahaṇādhikāra* and *sūryagrahaṇādhikāra* of later *siddhāntas*.

The system of astronomy taught in the *Āryabhaṭīya* is sometimes called the *audayika* inasmuch as the day beginning is reckoned from sunrise at Laṅkā. From Varāhamihira, Brahmagupta and others we learn that Āryabhaṭa was the originator of another, the *ārdharātrika* system, in which the day is reckoned from midnight at Laṅkā. Varāha's statement on this is as follows: 'Āryabhaṭa maintains that the beginning of the day is to be reckoned from midnight at Laṅkā; and the same teacher again says that the day begins from sunrise at Laṅkā.' Brahmagupta, in his *Brāhmasphuṭa-siddhānta*, also mentions Āryabhaṭa as the author of the sunrise and the midnight systems and himself followed the latter, along with its astronomical elements, in writing his *Khaṇḍakhādyaka*. Thus, although a great critic of Āryabhaṭa, Brahmagupta himself preserved for posterity his rival's *ārdharātrika* system. Al-Bīrūnī mentions that Āryabhaṭa also wrote a *tantra*, but this work has not come down to us. It is possible that the same *Āryabhaṭīya* was meant as it also came to be known as a *tantra* (Bhāskara I).

Of the direct pupils of Āryabhaṭa, the names of Pāṇḍurāṅgasvāmī, Lāṭadeva, Prabhākara and Niḥśaṅku are mentioned by Bhāskara I. Lāṭadeva, the expounder of the old *Romaka-* and *Sūrya-siddhānta*, earned the appellation '*sarvasiddhānta-guru*' and was held in high esteem by Varāha. But the man who appears to have contributed most to the propagation of Āryabhaṭa's astronomy, both through commentaries and independent works based on his master's principles and parameters, was Bhāskara I, a contemporary of Brahmagupta and himself an accomplished astronomer. In the eighth century Lalla wrote a work based on the *Āryabhaṭīya*. Some of the medieval commentators include Bhūtaviṣṇu, Nīlakaṇṭha Somasutvan, Parameśvara, Sūryadeva and Yallaya.

Varāhamihira (*c*. A.D. 505)

The author of the *Pañcasiddhāntikā* we have discussed above appears more as a compiler and a historian of astronomy than as an astronomer of originality. Nevertheless such a compiler could be an astronomer of no mean order. He was, however, more well known as an astrologer and wrote compendious astrological treatises such as *Bṛhatsaṃhitā*, *Bṛhajjātaka*,

Laghujātaka and *Yogayātrā*. According to Bhaṭṭotpala, Varāha had originally belonged to Magadha and later on lived and worked in Ujjayinī. He flourished in the middle of the sixth century A.D. His astrology and *horāśāstra* (horoscopes) were of Greek origin, and it is therefore not surprising that his works abound in Greek technical terms.

Bhāskara I (*c.* A.D. 600)

The greatest exponent of Āryabhaṭa's system of astronomy, Bhāskara I was a contemporary of Brahmagupta. T. S. Kuppanna Sastri placed him between A.D. 550 and 628. Shukla showed that he lived beyond this limit, his commentary on the *Āryabhaṭīya* being written in A.D. 629. Stray references to his works appear to indicate his association with Surāṣṭra (Western India) and Aśmaka (South India, possibly Kerala). It is possible that he was a native of either of these two regions and migrated to the other.

Bhāskara I wrote three works, e.g. the *Mahābhāskarīya*, the *Laghubhāskarīya* and a *bhāṣya* on the *Āryabhaṭīya*. The *Mahābhāskarīya* is an elaborate exposition of the three astronomical chapters of the *Āryabhaṭīya*, arranged in eight chapters devoted to the following topics: (1) Mean longitude of planets and indeterminate analysis (*kuṭṭaka*); (2) Longitude correction; (3) Time, place and direction, spherical trigonometry, latitudes and longitudes of junction-stars; (4) True longitudes of planets; (5) Solar and lunar eclipses; (6) Rising, setting and conjunction of planets; (7) Astronomical constants; and (8) *tithi* and miscellaneous examples. The work is occasionally characterized by innovations and the author's own methods. For example, to find the mean longitudes of planets, the *śīghra* of venus and mercury and the perigee and node of the moon, Bhāskara I gives a new method called the *pratyabda-śodhana*. It is true Āryabhaṭa gave rules for indeterminate analysis (*kuṭṭaka*), but it was the unquestionable merit of Bhāskara I to fully explain the method and its application to astronomy. In his formulą for the equation of the centre, he uses *manda karṇa* or hypotenuse to obtain the correction more accurately, whereas other Indian astronomers remained generally satisfied with the approximate value due to the use of the radius only.

The *Laghubhāskarīya*, as the name implies, is an abridged version of the author's fuller work noticed above. Intended for the beginner, its treatment is more systematic. His *Bhāṣya* is an elaborate and at the same time a learned commentary on the *Āryabhaṭīya* and abounds in quotations from *Vyākaraṇa*, *Vedānta*, *Mīmāṃsā*, *Arthaśāstra*, *Manusmṛti* and similar texts. The great popularity of Bhāskara's works, particularly in the south, is attested by several extant commentaries, of which mention should be made of those by Govindasvāmin (*c.* 800–850), Śaṅkaranārāyaṇa (*c.* 825–875), Udayadivākara (*c.* 1073) and Parameśvara (*c.* 1360–1460).

Brahmagupta **(*c.* A.D. 598)**

In his ***Brāhmasphuṭa-siddhānta***, Brahmagupta states that he was the son of Jiṣṇugupta, lived in the reign of King Vyāghramukha, and composed

this astronomical work in Śaka 550 (A.D. 628) at the age of 30. According to al-Bīrūnī, Brahmagupta was from Bhillamala, a town between Multan and Ahilwara. Bühler identified Bhillamala with modern Bhīnmāl or Śrīmāl near the northern frontier of Gujarat.

The *Brāhmasphuṭa-siddhānta* is a voluminous work comprising 1,008 verses (or 1,022 verses if the last chapter on generalities is included) and divided into 24 chapters. The main astronomical topics are dealt with in the first 10 chapters in the following order: mean planetary motions, true planetary motions, problems of time, space and distance, lunar and solar eclipses, risings and settings of planets, the moon's cusps and shadows, conjunctions of planets. Some of these topics are further discussed in chapters 13–17, 19–21. Chapter 22 is devoted to astronomical instruments. Chapters 12 and 18 deal with mathematics and reveal Brahmagupta's excellence and originality as a mathematician.

The chapter 11, entitled *Tantra-parīkṣādhyāya* (examination of other astronomical systems), is full of historical importance. Fully conscious of his own abilities, Brahmagupta criticized the views of, and rules and methods given by, other astronomers, notably Āryabhaṭa I, Śrīṣena, Viṣṇucandra, Lāṭa and Pradyumna. He was also very critical of foreign astronomical concepts and elements which by then had found their way into Indian astronomical works. He rejected the five-year *yuga* system of the *Vedāṅga Jyotiṣa* and criticized the absurd views of the Jainas who believed in the two suns and moons and two sets of *nakṣatras*. His undue bitterness towards Āryabhaṭa did not fail to attract the notice of al-Bīrūnī who, in spite of his regard for Brahmagupta, freely acknowledged the merit of Āryabhaṭa and his school. Brahmagupta attacked Āryabhaṭa for dividing the *yuga* into four equal parts, for upholding the rotatory motion of the earth, for believing in the eclipses being caused by the shadows of the moon and the earth and not in accordance with the traditional *Rāhu-Ketu* theory. All this is understandable if we remember that he followed in the main the *Brahma-siddhānta* and wrote his work at the age of 30 when he was certainly an enthusiastic supporter of the orthodox view.

From this position he certainly travelled a long way when he composed at the age of 67 his *Khaṇḍakhādyaka*, based principally on Āryabhaṭa's *ārdharātrika* system. Compared to his earlier work it is a small tract in eight chapters, to which a small appendix (*Uttara Khaṇḍakhādyaka*) is added. Here the mathematical chapters are omitted and purely astronomical topics are dealt with in the following order: *tithis* and *nakṣatras*; mean and true places; time, space and direction; lunar and solar eclipses; rising and setting of planets; the moon's cusps; conjunction of planets. Although he reconciled himself, by and large, to Āryabhaṭa's system, he nevertheless followed his own rules in a number of cases, which he considered to provide better and more accurate results. He gave methods for finding the instantaneous daily motion of planets affected by *manda* and *śīghra* inequalities, correct equations for parallax in longitude and latitude, correct equations

for *dṛkkarma* and better expressions for *valana*. In all this a better mathematician was obviously at work.

Brahmagupta's works played an important part in the introduction among the Arabs of a new mathematics-based astronomy. Both *Brāhmasphuṭa-siddhānta* and *Khaṇḍakhādyaka* were translated into Arabic, with the assistance of Hindu pandits, by Muhammad ibn Ibrāhīm al-Fazārī (d. 796 or 800) and Ya'qūb ibn Ṭāriq (d. 796) under the Arabic titles of *Sindhind* and *Arkand* respectively. These early Arabic translations were defective and corrupt, but none the less exerted a great influence among the Arab scholars. Indian commentators of Brahmagupta include Pṛthūdakasvāmī, Āmarāja, Bhaṭṭotpala, Lalla, Someśvara, Śrīdatta and Varuṇa. Pṛthūdakasvāmī commented on both the works, whereas the rest concentrated on his *Khaṇḍakhādyaka* only, which incidentally proves its greater popularity.

Vaṭeśvara (b. A.D. 880), *Mañjulācārya (c.* A.D. 932), *Āryabhaṭa II (c.* A.D. 950), *Śrīpati (c.* A.D. 999), *Śatānanda (c. eleventh century)*

Several astronomers flourished between the time of Brahmagupta and Bhāskara II (twelfth century), who made varying contributions to the subject. Of them mention may be made of Vaṭeśvara, Mañjulācārya (also called Muñjāla), Āryabhaṭa II, Śrīpati and Śatānanda. Vaṭeśvara's importance lies mainly in his criticism of Brahmagupta. A follower of Āryabhaṭa's system, he attacked Brahmagupta in the same manner as the latter had attacked his master about 250 years before. The chapter 10 of section 1 of his *Vaṭeśvara-siddhānta* is devoted exclusively to criticizing and refuting the views of Brahmagupta. The book is written in three principal sections, e.g. mean motions, true motions and problems of time, space and distance, each divided into a number of chapters. From his own statement we learn that he was the son of Mahādatta Bhaṭṭa, a native of Ānandapura in the Panjab, and was born in śaka 802. Author of *Laghumānasa* in six chapters, Mañjulācārya introduced into Indian astronomy the corrections due to the precession of the equinoxes. This precession is in the sense of retrograde motion and not of oscillation, as we have already noticed. The author of one *Ārya-siddhānta* or *Mahā-siddhānta* calls himself Āryabhaṭa who flourished about the middle of the tenth century. The work is composed in 18 chapters and devoted to familiar astronomical topics. It has a special chapter on *kuṭṭaka*, i.e. integral solutions of indeterminate equations of the first degree. Āryabhaṭa II was a compiler and did not possess the merit of his illustrious predecessors. He did not also follow Āryabhaṭa I, but adhered instead to the orthodox views. He mentioned the precession of the equinoxes. Śrīpati, son of Nāgadeva, is well known for his *Dhīkoṭī*, a *karaṇa* work based on the *Āryabhaṭīya*, a fuller astronomical work *Siddhānta-śekhara* divided into 20 chapters and his *Gaṇitatilaka*, a work on mathematics. Śrīpati considered, among other things, the moon's second inequality. Śatānanda flourished in the eleventh century in Puri

on the coast of the Bay of Bengal. His *Bhāsvatī* was composed more or less in imitation of the *Sūrya-siddhānta* and attained a measure of popularity among the almanac-makers. *Bhāsvatī* is a *karaṇa* work.

Bhāskara II (*b.* A.D. 1114)

Bhāskarācārya or Bhāskara II, to distinguish him from his namesake of the sixth/seventh century, was born in A.D. 1114 in Vījapur in the province of Karnata on the Western Ghats. His *Siddhānta-śiromaṇi* written in A.D. 1150 when he was 36 readily surpassed similar efforts by his predecessors in the field of astronomy and mathematics in lucidity of exposition, depth of treatment and occasional flashes of originality. The work is arranged in four parts, of which the first two, the *Līlāvatī* and the *Bījagaṇita*, deal with arithmetic and algebra respectively. Astronomy proper is treated in the two remaining sections, e.g. the *Gaṇitādhyāya* and the *Golādhyāya*. In the former section, the mean and the true motions of planets, the three problems relating to time, direction and place, the eclipses, risings, settings and the conjunctions of planets, etc., are treated in the same sequence as met with in the *Sūrya-siddhānta*. The *Golādhyāya*, or the chapter on the sphere where the same problems reappear, is more important from the viewpoint of theoretical astronomy. The epicyclic-eccentric theories to account for planetary motions are fully developed. The astronomical instruments described in the *Yantrādhyāya* are more numerous and perfect than those given in the *Sūrya-siddhānta* and other works.

Sufficiently clear and detailed as his versified rules were, Bhāskara II wrote his own commentary *Vāsanābhāṣya* to further explain and illustrate his own rules wherever he thought necessary. In A.D. 1183, he wrote another work on planetary motions under the title *Karaṇakutūhala*. His works, both in their entirety and in parts, are available in a large number of manuscripts. Several commentaries were also produced later on by such medieval astronomers as Gaṇeśa, Lakṣmīdāsa, Munīśvara, Nṛsiṃha, Raṅganātha, Viśvanātha and others, which kept alive Bhāskara II's popularity for several centuries throughout the length and breadth of India.

SECONDARY WORKS AND COMMENTARIES

The Sanskrit astronomical literature of the medieval period is extremely rich in secondary works and commentaries. The majority of this class of literature, it is true, was produced after Bhāskara II particularly from the fourteenth or fifteenth century, but it is highly unrealistic to draw any such line of demarcation. It is not quite true that the astronomical literature produced after Bhāskara II was barren of originality. As we have seen, some of the original authors before the twelfth century appeared as excellent commentators. Bhāskara I himself spent much of his time in elucidating his master Āryabhaṭa's works. In the ninth century A.D. we have Brahmagupta's scholiast Pṛthūdakasvāmī (*c.* 864) who wrote two important commentaries, *Brāhmasiddhānta-vāsanābhāṣya* and *Khaṇḍakhādyaka-vivaraṇa*. In the same

century Govindasvāmī (*c.* 800–850) and his pupil Śaṅkaranārāyaṇa, of the Āryabhaṭa school in the south, elucidated the works of Bhāskara I. The former, in addition to his *Mahābhāskarīya-bhāṣya*, wrote a few other astrological tracts, whereas the latter commented upon the *Laghubhāskarīya*. At the beginning of the thirteenth century Āmarāja wrote a commentary on the *Khaṇḍakhādyaka*.

In the fourteenth century, Mahendra Sūrī (*c.* A.D. 1320), a disciple of Madana Sūrī and native of Vṛgupura, flourished in the court of Emperor Firoz Shah Tughlak as one of his principal court astronomers. He wrote a tract entitled *Yantrarāja* or *Yantrarājagama* which dealt with astronomical instruments based mainly on Persian sources, in the course of the following five chapters, *Gaṇita*, *Ghaṭanā*, *Yantraracanā*, *Yantraśodhana* and *Yantra-vicāraṇa*. His disciple Malayendu Sūrī prepared on it a gloss called *Yantrarājaṭīkā*.

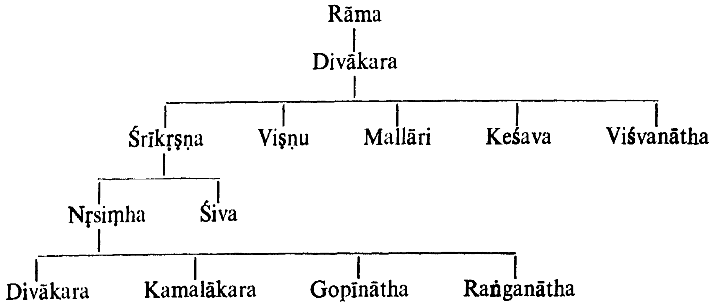
Towards the end of the fourteenth and the beginning of the fifteenth century there lived at Ālattur (lat. 10° 15′) on the Malabar coast Parameśvara, a versatile and prolific commentator, who is believed to have flourished between A.D. 1360 and 1460. He belonged to a family of astronomers and was a disciple of Rudra. His works include a commentary on the *Sūrya-siddhānta*, the *Sūrya-siddhānta-vivaraṇa*, the *Bhaṭadīpikā*, a commentary on the *Āryabhaṭīya*, the *Karmadīpikā* and the *Siddhāntadīpikā* on the *Mahābhāskarīya*, the *Laghubhāskarīya-vyākhyā* and the *Laghumānasa-vyākhya*, a gloss on Mañjula's work. Besides, he wrote a number of independent works, e.g. *Dṛggaṇita*, *Goladīpikā*, *Vākyakaraṇa* and *Grahaṇamaṇḍana*. Nīlakaṇṭha Somasutvan (1465–1545), the noted fifteenth-century commentator of the *Āryabhaṭīya*, was a disciple of Dāmodara, son of Parameśvara. This Nīlakaṇṭha, besides his *Āryabhaṭīya-bhāṣya*, one of the best commentaries available on the subject, wrote a number of independent astronomical works, e.g. *Tantra-saṃgraha*, *Siddhānta-darpaṇa*, *Candracchāyāgaṇita* and *Golasāra*. His works are marked by originality and refined methods of astronomical calculations. Some other commentators of this period include Gaṅgādhara, the author of *Candramāna* (A.D. 1434), who lived south of the Vindhyas, Makaranda of Banaras, the author of *Tithipatra* (A.D. 1478), a tract on handy tables based on the *Sūrya-siddhānta*, used extensively by the almanac-makers, and Lakṣmīdāsa, the author of *Gaṇitatattva-cintāmaṇi* (A.D. 1500), a commentary on the *Siddhānta-śiromaṇi*.

The production of secondary astronomical literature in the form of commentaries continued unabated in the sixteenth century, and we hear of a number of distinguished families of astronomers assiduously engaged in the task of propagating their science. Jñānarāja (*c.* A.D. 1503), son of Nāganātha, flourished at Pārthapura, a small village at the confluence of the Godāvarī and the Vidarbha. His *Siddhānta-sundara* is a full-fledged astronomical work in 18 chapters. His son Sūryadāsa was an accomplished commentator and wrote on Bhāskara II's *Līlāvatī* and *Bījagaṇita*. Gaṇeśa Daivajña (*c.* A.D. 1507) of Nandīgrām, a place about 40 miles from Bombay, attained eminence through his *Grahalāghava*, *Bṛhat-tithicintāmaṇi*,

Laghutithicintāmaṇi, *Siddhānta-śiromaṇi-vyākhyā* and a few other tracts. In his *Grahalāghava*, trigonometrical calculations were avoided and simpler arithmetical methods introduced instead. Bhāskara II had followed such simplified methods in his *Karaṇakutūhala* in the determination of shadows.

A Maharastrian brahmin, Divākara, son of Rāma and a disciple of Gaṇeśa Daivajña, established a line of astronomers whose activities continued for four generations. He was a native of Golagrām (lat. 18° N, long. 78° E) on the northern bank of the Godāvarī. A genealogical table showing the names of his sons, grandsons and great grandsons is given below. Of his five sons, Viṣṇu (b. A.D. 1566) wrote a *karaṇa* work entitled *Saurapakṣa-gaṇita*; Mallāri (b. 1571) produced a commentary *Siddhānta-rahasya* on *Grahalāghava* and other tracts; Viśvanātha (b. 1578) was a

Divākara Family



prolific writer producing commentaries on the *Sūrya-siddhānta*, *Grahalāghava*, *Karaṇakutūhala*, *Tithipatra*, *Siddhānta-śiromaṇi* and several other works. Divākara's grandson Nṛsiṃha (b. 1586), trained in astronomy by his uncles Viṣṇu and Mallāri, worked at Banaras and wrote the commentaries, the *Saurabhāṣya* and the *Vāsanāvārttika* on the *Sūrya-siddhānta* and the *Siddhānta-śiromaṇi* respectively. Of Nṛsiṃha's four sons, Kamalākara (b. 1616) made his mark through his *Siddhānta-tattvaviveka*, based largely on the *Sūrya-siddhānta*, in which were incorporated new materials from Arabic and Persian sources. His criticism of Bhāskara II and appreciation of Islamic astronomy led him into a bitter controversy with Munīśvara. Nṛsiṃha's youngest son Raṅganātha (*c.* 1640) is known for his *Siddhānta-cūḍāmaṇi*, a commentary on the *Sūrya-siddhānta* and his *Laghubhaṅgī-vibhaṅgī* written in refutation of Munīśvara's methods of finding true planetary positions.

Another reputed family of astronomers was represented by Vallāla who migrated from his ancestral home in Elachpur in Madhya Pradesa to Banaras. Of his five sons, Kṛṣṇa Daivajña (*c.* 1565) studied under Viṣṇu, son of Divākara of Golagrām, and wrote excellent commentaries on Bhāskara II's mathematical works. Kṛṣṇa's brother Raṅganātha (*c.* 1573) became well known for the *Gūḍhārtha-prakāśikā*, a commentary

on the *Sūrya-siddhānta*. Raṅganātha's son Munīśvara (b. 1603) wrote an astronomical work entitled *Siddhānta-sārvabhauma* and a commentary on the *Siddhānta-śiromaṇi*, called *Marīci*.

Sawāi Jai Sing II (1686–1734), *Jagannātha* (*b.* A.D. 1652)

In the beginning of the eighteenth century a new interest in astronomy was created by the efforts of Mahārājā Sawāi Jai Sing II of Jaipur, an able statesman, great scholar, skilled astronomer and patron of learning. He developed an interest in astronomy at an early age and assiduously studied the Hindu, the Arabic and the European systems of astronomy, as is evident from the rich collection of his library and biographical references. He was acquainted with the principles of Ptolemy's *Almagest* and Euclid's *Elements*, in Arabic versions, and knew well the works of Nasir al-Din aṭ-Ṭusi, al-Gurgānī, Jamshid Kāshī and Ulugh Beg, leaders of the Marāgha school of astronomers. That he came deeply under the influence of Arabic astronomy and methods of astronomical observations and planned his observatories after Marāgha, there seems to be little doubt. He also procured and studied some important European works of the day, such as Flamsteed's *Historia Coelestis Britannica*, la Hire's *Tabulae Astronomicae*, and miscellaneous mathematical works, including spherical trigonometry and logarithms.

Jai Sing's interest in astronomy was not merely theoretical. It was motivated by a strong desire to set up efficient modern observatories for improving upon the observational data and for producing more accurate astronomical tables. His principal Hindu astronomer Jagannātha informs us that he was skilled in the use of astronomical instruments and clever in exhibiting new methods with globes and instruments. He set up in Jaipur, Delhi, Ujjain, Banaras and Muttra astronomical observatories where a large number of his giant instruments such as the *Samrāṭ Yantra* (huge dials), *Jai Prakāś* (hemispherical dial), *Dakṣiṇovṛtti Yantra* (meridian circle), *Ṣaṣṭyaṃśa Yantra* (sextant), *Rāśi Yantra* (Zodiac dial), etc., were constructed in masonry. The results of observations carried out under his direction by his team of astronomers formed part of his astronomical table, the *Zīj Muhammad Shāhī*, prepared both in Persian and in Sanskrit. About the need for improved observations, the *Zīj* records as follows:[a]

> 'He (Jai Sing) found that the calculation of the places of the stars as obtained form the tables in common use, such as the new tables of S'aid Gurgānī and Khāquani, and the Tasahīlāt-Mula Chānd Akbar Shāhī and the Hindu books, and the European tables, in very many cases give them widely different from those determined by observation: especially in the appearance of the new moons, the computation does not agree with observation.'

* * *

[a] Hunter, pp. 118 ff.; *see also* Kaye (1), pp. 9–19.

'Although this was a mighty task, which during a long period of time none of the powerful Rājās had prosecuted; nor among the tribes of Islam, since the time of the martyr prince, whose sins are forgiven, Mirza Ulugh Beg, to the present, which comprehends a period of more than three hundred years, had any one of the kings possessed of power and dignity turned his attention to this object...'.

The reasons for constructing massive instruments in masonry instead of going in for brass and metal instruments which the Arab astronomers preferred are given as follows:

'But finding that brass instruments did not come up to the ideas which he had formed of accuracy, because of the smallness of their size, the want of division into minutes, the shaking and wearing of their axes, the displacement of the centres of the circles, and the shifting of the planes of the instruments, he concluded that the reason why the determinations of the ancients, such as Hipparchus and Ptolemy, proved inaccurate, must have been of this kind.

'Therefore he constructed in Dār al-Khalafat Shāh Jahānābād (Delhi), which is the seat of empire and prosperity, instruments of his own invention, such as *Jai Prakāś* and *Rām Yantra* and *Samrāṭ Yantra*, the semi-diameter of which is of eighteen cubits and one minute on it is a barley corn and a half—of stone and lime in perfect stability, with attention to the rules of geometry and adjustment to the meridian and to the latitude of the place, and with care in the measuring and fixing of them, so that the inaccuracies from the shaking of the circles and the wearing of their axes and displacement of their centres and the inequality of the minutes might be corrected. Thus an accurate method of constructing an observatory was established and the difference which had existed between the computed and observed places of the fixed stars and planets by means of observing their mean motions and observations was removed.'

Significant as his efforts were in establishing and developing observational astronomy, Jai Sing's importance lay in his realization of the fact that the progress of science depended on drawing upon knowledge and know-how from wherever these were found. A patron of Hindu science and learning, he admired Arabic astronomy and did not hesitate to turn to Christian Europe as soon as he learnt of the efforts of their savants in the science of the heavens. In 1728 or 1729 he sent Father Figueredo, a Portuguese Jesuit, to Europe to collect astronomical information and literature. He invited to Jaipur Father Boudier, a French Jesuit missionary of Chandernagore, who was an able astronomer and had determined accurately the longitude of Chandernagore.

His principal court astronomer was Jagannātha (*b.* A.D. 1652) who, at the instance of his patron, mastered Arabic and Persian and translated Ptolemy's *Almagest* and Euclid's *Elements* from their Arabic versions into Sanskrit. The *Samrāṭ-siddhānta*, the Sanskrit title of the *Almagest*,

contained 13 chapters, 141 sections and 196 geometrical propositions. The *Rekhāgaṇita* was the name given to the *Elements*. Hunter records that at Ujjain he met a grandson of Jagannātha and found in his possession several Sanskrit translations of European mathematical works, including Euclid's geometry, plane and spherical trigonometry and Napier's logarithms.

The good start made by Jai Sing and the excellent work done by the people he gathered round him came to an abrupt end at his untimely death in 1743.

SOME ASTRONOMICAL TOPICS IN THE *SIDDHĀNTAS*

In this section we shall deal with some of the salient features of Hindu mathematical astronomy as generally taught in the various texts summarized in the foregoing section.

THE SPHERE AND THE COORDINATES, DIRECTION, PLACE AND TIME

In all the texts the earth is assumed to be an immovable sphere at the centre of the universe. The asterisms with the sun, the moon and other planets have a retrograde motion, that is from east to west, completing the circle in a day; the sun, the moon and the planets have a direct motion of their own, that is from west to east, as a result of which they are constantly beaten by the asterisms and fall behind them. As we have noticed previously, Āryabhaṭa showed that the apparent daily retrograde motion can be explained by the direct rotation of the earth, a view opposed by other Hindu astronomers.

The Sphere and some Important Great Circles

To represent the positions and motions of the planets, stars and heavenly bodies, a celestial sphere of an arbitrary radius R is imagined, at the centre of which lies the earth or the observer. A vertical line through the observer meets the celestial sphere above and below at points Z, Z' (Fig. 2.1) called the zenith (*ūrdhva svastika*) and the nadir (*adha svastika*). The plane passing through the observer O at right angles to the vertical line ZZ' cuts the celestial sphere in a great circle $NESW$, called the observer's celestial horizon (*kṣitija*). The horizon passes through the four cardinal points, north, east, south and west. Thus Varāhamihira in his *Pañcasiddhāntikā*[a] says: 'That (circle) in which the sky is joined as it were to the earth is called "horizon"; in it are drawn east-west and north-south lines.' Varāha used the term *harija* for horizon.

The east-west and the north-south lines are easily determined by observing the points where the shadow of the gnomon touches a circle drawn on

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[a] *PSi.*, xiv. 17.

the horizontal plane in the forenoon and in the afternoon. The line joining these two points is parallel to the east-west line passing through *O*; the north-south line passing through *O* is perpendicular to the former. All Hindu texts give clear rules for finding these cardinal directions.

The great circle *NZSZ'* passing through the north-south points and the zenith and the nadir is the meridian (*yāmyottara-vṛtta*). The great circle *EZWZ'* through the east-west points and the zenith and the nadir is called the prime vertical (*sama-maṇḍala*). Brahmagupta, in his *Brāhma-sphuṭa-siddhānta*,[a] defines these circles as follows: 'One circle called the *sama-maṇḍala* has its plane stretching east and west; another lying north and south is called the *yāmyottara-vṛtta*; another termed the *kṣitija* encircles the other two like a girdle. At the common centre of these circles is situated the observer on the earth.'

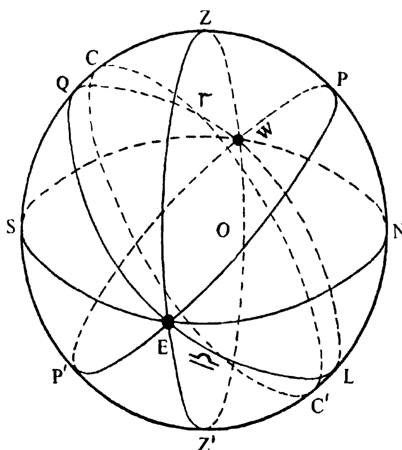


FIG. 2.1 The celestial sphere and some important great circles.

In Fig. 2.1, the great circle *QELW* represents the celestial equator (*viṣuvanmaṇḍala*) of which the poles are *P*, *P'*. The angular distance of the pole from the horizon equals the latitude ϕ of the observer, which is equal to the zenith distance of *Q*, the point where the celestial equator meets the meridian. Brahmagupta defines the equator as the circle which meets the horizon at the east-west points and of which the top lies to the south of the prime vertical by the latitude of the observer, and the bottom as much to the north of it. Varāhamihira defines the interval between the pole and the horizon as the terrestrial latitude of the observer. Diurnal motions of planets and stars are represented by small circles parallel to the equator.

[a] *Br.Sp.Si. Gola.*, 48.

Of the hour circles or secondaries to the equator special importance attaches to the 6 o'clock circle passing through the pole and the east-west points. In Hindu astronomy this is called *unmaṇḍala* which, as Āryabhaṭa says, is above and below the horizon by the amount of the observer's latitude. The increase and the decrease of the day and night are measured on this circle.

Finally, we have the ecliptic (*apamaṇḍala*) which is inclined to the equator at an angle of 24°, meeting later at the first point of Aries (*Meṣa*) and the first point of Libra (*Tulā*). Āryabhaṭa states that the northern half of the ecliptic is from the beginning of *Meṣa* to the end of *Kanyā* and its southern half is from the beginning of *Taulya* to the end of *Mīna.*[a]

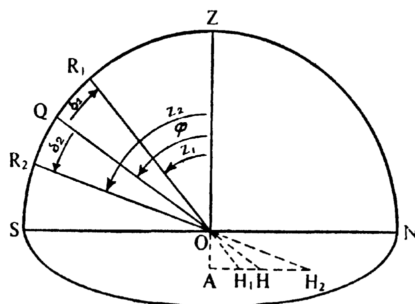


FIG. 2.2

Coordinates

In representing the positions of celestial bodies, the horizontal, the equatorial and the ecliptic systems are used. In the horizontal system, the altitude (*unnata*) or the zenith distance (*nata*) is defined as in modern astronomy, but the azimuth is reckoned from the prime vertical either from the east or the west point on the horizon, but never exceeding 90°. The azimuth circle is called the *dṛgmaṇḍala* and the azimuth the *digaṃśa*. In the equatorial system, the two coordinates are the declination or *krānti* and the hour angle. *Krānti* is the angular distance of the body from the equator measured along its secondary through the body. Hour angle is measured in two ways, either by the *unnata-ghaṭi* (time-altitude) or by *nata-ghaṭi*. *Unnata-ghaṭi* is the hour angle between the declination circle through the body and that through its rising point on the horizon; *nata-ghaṭi* is the hour angle between the declination circle through the body and the meridian. In the ecliptic system, the position of a body is given by its latitude (*vikṣepa*) and its longitude (*sphuṭa*) measured from the fixed point marked by Zeta Piscium (*Revatī*).

[a] *Ā. Gola.*, 1.

Latitude, Zenith Distance and Declination

When the sun is at either of the equinoxes, its meridional zenith distance is equal to the latitude of the observer. This is easily determined by measuring the equinoctial shadow (*viṣuvatprabhā*, *palabhā*, etc.) AH, cast by the gnomon OA (Fig. 2.2).

$$\text{Let } OA = g,\ AH = S_e,\ OH = h$$

$$\therefore\ h = \sqrt{g^2 + S_e^2}\,.$$

The latitude (*akṣa*), ϕ, and the colatitude (*lamba*), $90-\phi$, are given by

$$R \sin \phi = \frac{RS_e}{\sqrt{g^2+S_e^2}};\quad R \sin (90-\phi) = \frac{Rg}{\sqrt{g^2+S_e^2}}.$$

Also

$$S_e = \frac{g \sin \phi}{\sin (90-\phi)}.$$

The *Sūrya-siddhānta*[a] gives the above rules as follows: 'Radius multiplied respectively by the equinoctial shadow and the gnomon and then divided by the equinoctial hypotenuse gives the sine of latitude and the sine of colatitude.'

For any declination δ_1 north of the equator or δ_2 south of the equator, the meridional zenith distances Z_1 and Z_2 are given by[b]

$$R \sin Z_1 = \frac{RS_1}{h_1}$$

$$R \sin Z_2 = \frac{RS_2}{h_2}$$

where S_1, S_2 are the shadows and h_1, h_2 are the corresponding hypotenuses of the gnomon. From Fig. 2.2,

$$\phi = Z_1 + \delta_1$$

$$\phi = Z_2 - \delta_2$$

that is,

$$\phi = Z \pm \delta.$$

Thus the declination of the sun can be found from the latitude of the place and the meridional zenith distance. In this way the maximum declination or the obliquity of the ecliptic with the equator, given in Hindu astronomical texts as 24°, must have been determined.

Relation between the Declination, the Longitude and the Obliquity of the Ecliptic with the Equator

The *Sūrya-siddhānta*[c] gives the relation between declination, the longitude and the obliquity of the ecliptic with the equator as follows: 'The sine of the greatest declination is thirteen hundred and ninety-seven;

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[a] *Sū. Si.*, iii. 13, 14, 16, 17. [b] *Sū. Si.*, iii. 15. [c] *Sū. Si.*, ii. 28.

by this multiply any sine, and divide by radius; the arc corresponding to the result is said to be the declination.' According to Bhāskara I,[a] the R sine of the given longitude, multiplied by 1397 and divided by the radius, yields the R sine of the declination for that instant of time.

The relationship may be expressed as follows:

$$R \sin \delta = \frac{1397 . R \sin \lambda}{R} = \frac{R \sin \epsilon . R \sin \lambda}{R}$$

where δ = declination of the sun; ϵ = obliquity of the ecliptic with the equator = 24°; $R \sin \epsilon = 1397'$; λ = longitude of the sun, that is the sun's angular distance from the first point of Aries along the ecliptic; R = radius of the sphere = 3438′. The above formula follows readily from the properties of the spherical triangle as also from the geometry of the similarity of triangles (Fig. 2.3).

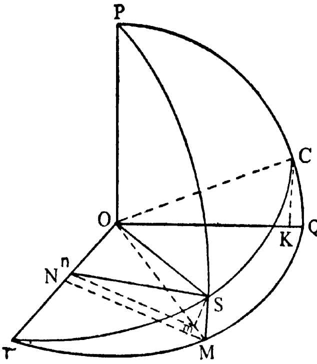


Fig. 2.3

ΥMQ = equator;
ΥSC = ecliptic;
S = the sun;
$\Upsilon S = \lambda$ = longitude of the sun;
$S\Upsilon M = CQ = \epsilon$ = obliquity;
$SM = \delta$ = declination of the sun.
$\Delta^s COK$, Snm are similar.

$$\therefore \frac{Sm}{Sn} = \frac{CK}{OC}$$

$$\therefore \frac{R \sin \delta}{R \sin \lambda} = \frac{R \sin \epsilon}{R}$$

$$\therefore R \sin \delta = \frac{R \sin \epsilon . R \sin \lambda}{R}$$

Since ϵ is known, this formula can be applied to find out the longitude of the sun from its declination.

The Ascensional Difference or Cara

The formula for finding the ascensional difference or *cara* affords yet another example of the skilful use of the celestial sphere and its circles. The ascensional difference is variously defined as the difference between the right ascension and oblique ascension of a rising point on the ecliptic or the difference between the times of the rising of the sun on the horizon and the 6 o'clock circle (*unmaṇḍala*). In Fig. 2.4(*a*), H is the rising point on the ecliptic ΥHC, Υ is the vernal equinox, ΥEQ is the equator and E the east point. The ascensional difference FE is clearly the difference between the oblique ascension ΥE and the right ascension ΥF of the rising point H. FE is also equal to the arc HG or $\angle HBG$ (Fig. 2.4(*b*)) which

[a] *MBh.*, iii. 6.

represents the time difference of the sun's risings on the horizon and the 6 o'clock circle.

In Fig. 2.4(*b*) (*see also* Fig. 2.4(*c*)), *NES* is the horizon, *EQ* the equator, *P* the pole, *Z* the zenith, *HGR* the diurnal circle of the sun (or star), *PGE* the 6 o'clock circle, $\angle PON$ = the latitude of the place, ϕ, and $\angle ROQ = \angle BRO$ = the declination of the sun (or star), δ. The two important elements in the above constructions are the radius *RB* of the diurnal circle, which is called the 'day radius' (*dinavyāsadala*) and the

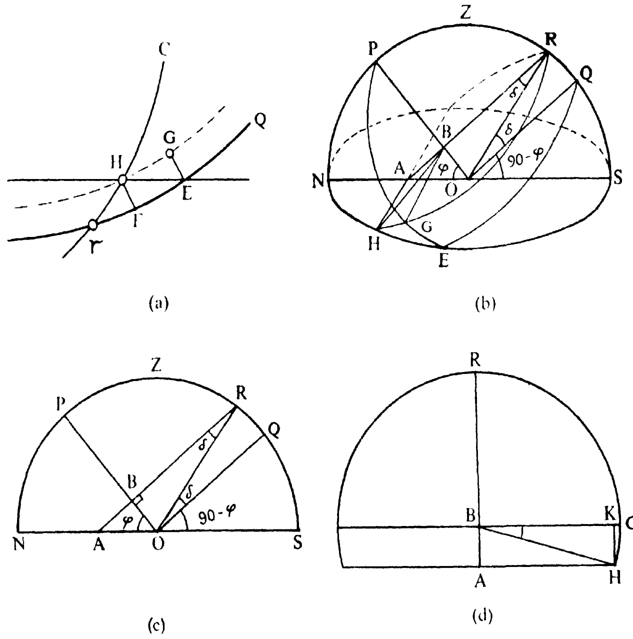


FIG. 2.4. Ascensional difference.

extra length *AB* intercepted between the plane of the horizon and that of the 6 o'clock circle; this length *AB* is called the earth sine (*kṣitijyā*). Now,

$$\text{day radius} = BR = R\cos\delta$$
$$\text{earth sine} = AB = OB\tan\phi = R\sin\delta\tan\phi.$$

The ascensional difference $\angle HBG$ (denoted by $\Delta\alpha$) is given by (*see* Fig. 2.4(*d*))

$$R\sin\Delta\alpha = \frac{R.HK}{BH} = \frac{R.AB}{BR} = \frac{R.R\sin\delta\tan\phi}{R\cos\delta} = R\tan\delta\tan\phi.$$

Also,

$$R\sin\Delta\alpha = \frac{\text{radius} \times \text{earth sine}}{\text{day radius}}.$$

This rule is expressed by Bhāskara I as: 'The earth sine multiplied by the radius and then divided by the day radius gives the arc called the ascensional difference (*caradala*) by the good astronomers.'

THE *AHARGAṆA* AND THE METHOD OF COMPUTING THE MEAN LONGITUDES OF PLANETS

We have seen that since the time of composition of astronomical *siddhāntas* all Hindu texts give as a rule the number of revolutions of each planet in a *mahāyuga* as also the number of civil days in such a *yuga*. Thus we know the time period in civil days of the revolution of each planet. At the beginning of the *mahāyuga* or at the commencement of special epochs such as the *Kaliyuga* all planets were in conjunction at the initial point of the sphere, that is their longitudes were zero. If the number of civil days elapsed from the beginning of an epoch up to any point of time is found, the mean longitude of any planet can be calculated by dividing the elapsed civil days by the time period of the planet. The quotient will give the number of times the planet returned to the initial point and the remainder expressed in degrees, minutes and seconds the mean longitude. If the reckoning is made from any other arbitrarily chosen epoch, it will be necessary to know the longitudes of planets at the beginning of such an epoch.

The number of civil days elapsed during any interval of time is called *ahargaṇa*. Where dates are kept according to a solar calendar, the *ahargaṇa* can be found simply by counting the days. But the difficulty arises when dates are given according to a luni-solar calendar. In a luni-solar calendar, a *saura* year is defined as the time taken by the sun to travel through the 12 signs of the zodiac (or ecliptic), the lunar month is the time interval between two new moons and the day is reckoned by the *tithi* or lunar day which is one-thirtieth of the lunar month. A lunar month has 29·5 days so that 12 lunar months contain 354 days and 13 lunar months 384 days approximately; in other words, a *saura* year cannot contain an integral number of lunar months, necessitating some years to consist of 12 and some of 13 months. The 13th month is an intercalary month. In the *ahargaṇa* calculations, as we shall presently see, it is necessary to know the number of such intercalary months in a *mahāyuga*. A *saura* month is the time taken by the sun to travel through one sign so that there are 12 *saura* months in a year. The number of *saura* months in any given length of time is the difference between the numbers of lunar and intercalary months.

A lunar month has 29·5 civil days and 30 lunar days, which means that the lengths of a civil and a lunar day are different. Thus, a year of 12 lunar months contains 354 civil (*sāvana*) days and 360 lunar days, that is more lunar days than the civil days. Such extra lunar days are called 'omitted *tithis*' or 'omitted lunar days' (*kṣayāha*). Therefore, in any given

length of time, the number of civil days is the difference between the number of lunar days and the number of omitted lunar days.

Suppose we are required to calculate the *ahargaṇa*, that is the number of civil days elapsed in time t.[a] Let t be y years, m months (lunar) and d days (lunar); y may be expressed in *Śaka* era or in *Kaliyuga* era, the relation between the two eras being

year 3,180 *Kaliyuga* = year 1 *Śaka*.

Other symbols used in this calculation are:

m_s = number of *saura* months in time t;
m_l = number of lunar months in time t;
m_i = number of intercalary months in time t;
d_l = number of lunar days in time t;
d_o = number of omitted lunar days in time t;
d_s = number of *saura* days in time t;
M_s = number of *saura* months in a *mahāyuga*;
M_l = number of lunar months in a *mahāyuga*;
M_i = number of intercalary months in a *mahāyuga*;
D_l = number of lunar days in a *mahāyuga*;
D_o = number of omitted lunar days in a *mahāyuga*;
D_s = number of *saura* days in a *mahāyuga*;
a = *ahargaṇa* in time t.

Ahargaṇa, by definition, is given by

$$a = d_l - d_o \quad \ldots \quad (1)$$

Now, $d_l = 30m_l + d$ .. (2.1)

or $d_l = 30(m_s + m_i) + d, \quad \because m_l = m_s + m_i$ .. (2.2)

or $d_l = 30(12y + m + m_i) + d, \quad \because m_s = 12y + m$ .. (2.3)

or $d_l = [30(12y + m) + d] + 30m_i$ .. (2.4)

or $d_l = d_s + 30m_i$, where $d_s = 30(12y + m) + d$ .. (2.5)

m_i and d_o are determined from the following ratios:

$$\frac{m_i}{d_s} = \frac{M_i}{D_s} \quad \ldots \quad (3)$$

Also from

$$\frac{m_i}{m_s} = \frac{M_i}{M_s} \quad \ldots \quad (3.1)$$

$$\frac{d_o}{d_l} = \frac{D_o}{D_l}. \quad \ldots \quad (4)$$

The total numbers of intercalary months M_i, *saura* months M_s, *saura* days D_s, lunar days D_l and omitted lunar days D_o in a *mahāyuga* are given as constants in all Hindu astronomical texts from which the above-mentioned ratios can be calculated. In the *Pañcasiddhāntikā* these values are given not for the *mahāyuga*, but for a different cycle. From m_i, d_l and d_o and hence *ahargaṇa* a can be found out.

[a] Bhattacharyya and Sen, pp. 144–155.

According to *Pañcasiddhāntikā* (*Romaka*), $m_t = m_s \dfrac{7}{228}$.

According to *Sūrya-siddhānta*, $m_t = m_s \dfrac{M_t}{M_s}$

$$= m_s \frac{1{,}593{,}336}{51{,}840{,}000}.$$

According to *Khaṇḍakhādyaka*, $m_t = \dfrac{d_s}{976}\left[1 - \dfrac{1}{14{,}945}\right]$.

d_o is given in the various texts as follows:

According to *Pañcasiddhāntikā* and *Sūrya-siddhānta*, $d_o = \dfrac{11}{703} d_l$.

According to *Khaṇḍakhādyaka*, $d_o = \dfrac{11}{703}\left[1 - \dfrac{1}{111{,}573}\right] d_l$.

Thus d_l and d_o being fully known, their difference will give the required *ahargaṇa*.

PLANETARY THEORIES

The planets, along with other celestial bodies, appear to move west, daily rising in the east and setting in the west, these revolutions taking place parallel to the celestial equator. In this apparent western motions, the planets are, however, constantly beaten by the asterisms and fall behind. In other words, with reference to the stellar frame, the planets really move eastward along the ecliptic with different angular velocities. The Hindu astronomers believed that the linear speeds of planets, in *yojanas*, are all equal, with the result that the planets describing orbits closer to the earth apparently move more swiftly than those describing these orbits at greater distances from the earth. The planets in the ascending order of distances from the earth are the moon, mercury, venus, sun, mars, jupiter and saturn. 'The moon being below', writes Āryabhaṭa,[a] 'completes its small orbit in a short time. Saturn being above all others completes its large orbit in a long time.' He says further on, 'The zodiacal signs (a twelfth of the circle) are to be known as small in a small circle and large in a large circle. Likewise the degrees and minutes are the same in number in the various orbits.'[b] These imply the necessity of dealing with angular distances in describing planetary motions.

In their direct motion, that is from west to east, the planets appear sometimes to move slowly, very slowly, fast and very fast. Sometimes, their motions appear even retrograde. The *Sūrya-siddhānta*[c] describes such peculiar planetary motions in the following manner:

vakrānuvakrā kuṭilā mandā mandatarā samā |
tathā śīghratarā śīghrā grahāṇāmaṣṭadhā gatiḥ ||

---

[a] *Ā. Kāla.*, 13. [b] *Ā. Kāla.*, 14. [c] *Sū. Si.*, ii. 12.

'The motion of the planets is of eight kinds: retrograde (*vakra*), somewhat retrograde (*anuvakra*), transverse (*kuṭila*), slow (*manda*), very slow (*mandatara*), even (*sama*), also very swift (*śīghratara*), and swift (*śīghra*).'

We now know that all these apparent peculiarities are due primarily to the following: (1) the planets excepting the moon revolve in orbits of which the centre is not the earth, but the sun; (2) the earth and with it the observer revolve once a year about the sun; (3) in consequence of their distances, mercury and venus revolve round the sun in orbits smaller than the earth's; these are called inferior planets; mars, jupiter and saturn, called superior planets, revolve in orbits larger than the earth's; (4) the planetary orbits are really not circles but ellipses with the sun at either focus.

To the ancients, firmly entrenched in their belief in the immobility of the earth, a heliostatic explanation of such planetary irregularities was clearly impossible. Although the Pythagoreans, Aristarchus of Samos and a few others in antiquity had favoured a heliostatic model, such a model was not used for planetary explanations. On the other hand, several geostatic schemes were devised, of which the eccentric-epicyclic model ultimately came to dominate ancient and medieval astronomy up to the time of Copernicus. The geometric eccentric and epicyclic methods and their applications to planetary motions were in all probability discovered by Apollonius of Perga (*c*. 230 B.C.), utilized successfully by Hipparchus (*c*. 130 B.C.) to account for solar and lunar inequalities and most exhaustively dealt with and applied by Ptolemy (*c*. A.D. 140) in the development of his famous planetary theories. The Hindus also adopted the eccentric-epicyclic model in the process of reconstruction of their astronomy during the first few centuries of the Christian era. It is likely that the Greek planetary theories of the period between Hipparchus and Ptolemy influenced the Hindu astronomers of the period engaged in the task of reforming their own system.

Eccentric Model

This model is represented by Fig. 2.5 in which ACP, $A'C'P'$ are two circles of equal radii, with centres at O and O'. $A'P$ passing through the two centres is the apse line. Let two bodies, one in each circle, move with the same angular velocity in direct, i.e. anti-clockwise direction, reaching A, A' or P, P' at the same time. To an observer at O the angular motion of C will appear uniform, but that of C' variable. By the time the body in the first circle has moved from A to C, the body in the

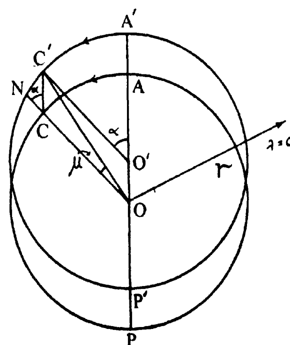


FIG. 2.5. Eccentric model.

second has moved from A' to C' such that $\angle\, COA = \angle\, C'O'A' = \angle\, NCC'$. But seen from O, C' has moved through the $\angle\, C'OA'$ and has fallen behind C by $\angle\, COC'$ or $\angle\, OC'O'$. As the two bodies approach P and P', C' will appear to the observer at O to move with greater angular velocity than C. Thus a body moving with uniform speed in an eccentric circle will appear from the centre to move more slowly at the apogee A' and more rapidly at the perigee P'.

Epicyclic Model

The same result can be obtained by the epicyclic model (Fig. 2.6) in which C' is moving in an epicycle of radius equal to OO', the distance between the two centres in the eccentric model (Fig. 2.5). C' is moving in the epicycle with the same angular velocity in retrograde, i.e. clockwise direction, as its centre C is moving on the concentric (or deferent circle) in anti-clockwise direction. It is clear that $\angle\, A'CC' = \angle\, COA$. $\angle\, COC'$ is the angle by which the body falls behind C and is the same as obtained by the eccentric model given above.

Fig. 2.6. Epicyclic model.

The Inequality of the Sun

The eccentric or the epicyclic method as described above can be readily applied to determine the inequality of the sun or any other planet due to apsis. The mean sun is supposed to revolve on the concentric ACP. Its longitude is reckoned from the first point of Aries γ ($\lambda = 0$). The true sun C' is moving in the circle $A'C'P'$ in the eccentric model or in the epicycle in the epicyclic model.

$\angle\, COA$ = mean longitude of sun − longitude of apogee
= mean anomaly = α

$\angle\, COC'$ = angular difference between mean sun and true sun
= equation of centre = μ

$OC = R$; $OO' = CC' = r$; $C'N$ is perpendicular to OC produced.

From simple trigonometry,

$$C'N = r \sin\alpha;\; CN = r\cos\alpha$$

$$C'O = \sqrt{(R+r\cos\alpha)^2+(r\sin\alpha)^2}$$

$$\sin\mu = \frac{r\sin\alpha}{\sqrt{(R+r\cos\alpha)^2+(r\sin\alpha)^2}}.$$

Assuming r to be negligible compared to R,

$$R \sin \mu = r \sin \alpha = \frac{R \sin \alpha \,.\, 2\pi r}{2\pi R} = \frac{(R \sin \alpha) \odot \mu}{360^\circ}$$

where $\odot\mu$ = circumference of the epicycle expressed in degrees.

This is the formula for the equation of centre as given in the *Sūrya-siddhānta* and other texts. Āryabhaṭa and his followers retained the full expression for $C'O$, the hypotenuse, without making the approximation by assuming r to be negligible. In Hindu astronomy the process is called *mandakarma*. The technical terms used for the various geometrical and trigonometrical elements involved in this method are as follows:

concentric in which the mean planet moves—*kakṣāvṛtta*
eccentric circle—*manda parivṛtta*
apse line—*nīcocca rekhā*
apogee, aux—*mandocca*
epicycle—*nīcocca vṛtta*
mean sun—*madhyama sūrya*
true sun—*sphuṭa sūrya*
mean anomaly, α—*mandakendra*
equation of centre, μ—*mandaphala*
$R \sin \alpha$—*mandakendrajyā, bhujajyā*
$R \sin \mu$—*mandaphalajyā*
$2\pi r$ or $\odot\mu$—*mandaparidhi, nīcocca vṛtta-paridhi*
$2\pi R$ or 360°—*bhaganāṃśa*.

The rule in the *Sūrya-siddhānta*[a] is given as follows:

$$mandaphalajy\bar{a} = \frac{bhujajy\bar{a} \times mandaparidhi}{bhagan\bar{a}\dot{m}\acute{s}a}\,.$$

The Planetary Schemes

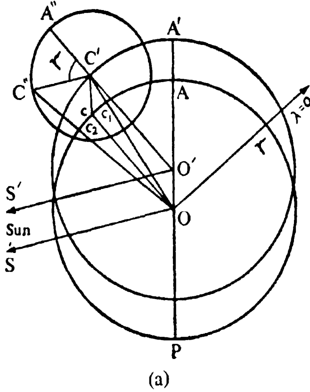
Motions of planets involve two inequalities, one due to planet's apsis and the other due to its conjunction with the sun. Planetary schemes must therefore be capable of dealing with both these inequalities satisfactorily. The following three schemes are possible:

(*a*) Eccentric-eccentric—both the inequalities are determined on eccentric model;
(*b*) Eccentric-epicyclic—the first inequality is obtained on the eccentric model and the second inequality on the epicyclic model;
(*c*) Epicyclic-epicyclic—both the inequalities are determined on epicyclic model.

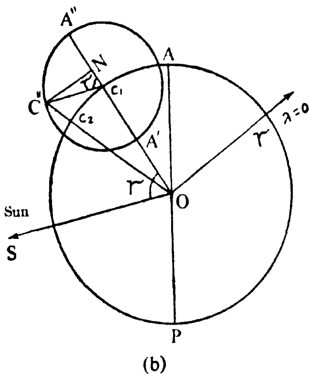
We shall here discuss only one of the three schemes, e.g. the eccentric-epicyclic model (Fig. 2.7(*a*), (*b*)). O is the centre of the concentric ACP (radius = R), A the apsis and OO' the eccentricity (r_1). If C be the mean

[a] *Sū. Si.*, ii. 39.

position of the planet on the concentric, its true position on the eccentric circle will be C' such that CC' is parallel to the line of apsis OA'. Join $C'O$ cutting the concentric at C_1. Then C_1 is the corrected position of the planet C and $\angle COC'$ or $\angle OC'O'$ is the equation of the centre.



(a)



(b)

FIG. 2.7. Eccentric-epicyclic model for finding the *śīghra* correction.

For the second inequality, an epicycle is drawn with C' as centre and radius r_2. $C'C''$ is drawn parallel to OS or $O'S'$, the direction of the sun. Join $C''O$ cutting the concentric at C_2. Then C_2 is the corrected position of the planet due to conjunction with the sun and $\angle C_2OC_1$ is the second inequality due to conjunction.

The net correction is really given by the $\angle COC_2$ and it is possible to derive an equation involving both the mean anomaly and the mean argument. But such a formula is unsuitable for the computation of correction tables. Both Ptolemy and Hindu astronomers, from practical considerations, preferred to calculate the two corrections separately and then combine them to obtain the true longitude.

The formula for calculating the first correction, i.e. the equation of centre, has already been given above. To find the second correction due to conjunction, called *śīghraphala* by the Hindus, a simplification is introduced. The centre of the epicycle is taken to be C_1 on the concentric (Fig. 2.7(*b*)) instead of at C'. The mean argument is also reckoned from the line OC_1 and not from OC or $O'C'$, the latter being the more correct procedure.

$\angle C_1OS = \angle C''C_1N =$ mean argument $= \gamma$
$\angle C_2OC_1 =$ correction due to conjunction $= \sigma$
radius of the concentric $= R$
radius of the epicycle $= r_2$ (r_1 being the eccentricity due to apsis).

Then, $$C''N = r_2 \sin \gamma\,;\ C_1N = r_2 \cos \gamma$$

$$OC'' = \sqrt{(r_2 \sin \gamma)^2+(R+r_2 \cos \gamma)^2}$$

and $$R \sin \sigma = \frac{R \,.\, r_2 \sin \gamma}{\sqrt{(r_2 \sin \gamma)^2+(R+r_2 \cos \gamma)^2}}.$$

The above method of finding the equation of the argument, that is the conjunction correction, is called *śīghrakarma*. The technical terms employed for the various geometrical and trigonometrical elements involved are as follows:

OS, the direction of the sun from the earth—*śīghra*
A'', the place of superior conjunction—*śīghra*
R, the radius of the concentric (*kakṣāvṛtta*)—*trijyā*
r_2, the radius of the conjunction epicycle—*śīghrāntyaphalajyā*
γ, the mean argument (also called anomaly)—*śīghrakendra*
$r_2 \sin \gamma$—*doḥphala, vāhuphala, bhujaphala*
$r_2 \cos \gamma$—*koṭiphala*
$R \sin \gamma$—*śīghrakendrajyā*
$R \cos \gamma$—*śīghrakendrakoṭijyā*
$R+r_2 \cos \gamma$ = *trijyā*+*koṭiphala* = *sphuṭakoṭi*

$$\sqrt{(r_2 \sin \gamma)^2+(R+r_2 \cos \gamma)^2} = \sqrt{(\textit{doḥphala})^2+(\textit{sphuṭakoṭi})^2} = \textit{karṇa}$$

σ = equation of argument—*śīghraphala*
$R \sin \sigma$ = *śīghraphalajyā*.

The Hindu formula for finding the equation of argument is simply expressed as follows:

$$\textit{śīghraphalajyā} = \frac{\textit{trijyā} \times \textit{doḥphala}}{\textit{karṇa}}.$$

THE SIZES OF THE SUN AND THE MOON, THEIR DISTANCES FROM THE EARTH, ECLIPSES AND PARALLAX

We have seen that from Vedic times the Indians were interested in the phenomena of solar eclipses. Good descriptions of them have been preserved in the *Brāhmaṇa* literature, but scientific studies of them were perfected in the *siddhānta* period. The mythological and the Purāṇic *Rāhu-Ketu* theory which had become firmly entrenched in the minds of laymen and even astronomers and continued long thereafter gave place to the scientific one based on the relative positions of the sun, the moon and the earth and the shadows cast by the moon on the earth or by the earth upon the moon. Contrary to the Purāṇic idea of *Rāhu* devouring the sun or the moon, Āryabhaṭa says: 'The moon obscures the sun and the great shadow of the earth obscures the moon. When at the end of the true lunar month (at new moon) the moon, being near the node, enters the sun, or when, at the end of half month (at full moon), the moon enters the shadow of the earth, that is the middle of the eclipse, which occurs sometimes before and sometimes after the exact end of the lunar month or half month.'[a] Varāhamihira explodes the *Rāhu-Ketu* myth and says that the real cause of a lunar eclipse is the entry of the moon into the earth's shadow and likewise at the solar eclipse the moon enters the sun.

[a] *Ā. Gola*, 37–38.

A very clear and lucid exposition of eclipses is given by Bhāskara II in his *Siddhānta-śiromaṇi*, section *Golādhyāya*, chapter *Grahavāsanā*. He says: 'The orbit of the moon is below that of the sun. Just as a cloud moving from behind covers the sun so does the moon moving faster covers the sun from behind. That is why the western part of the sun is eclipsed by the moon first and the eastern side released last. Owing to differences in the latitude eclipses are sometimes seen and sometimes missed.' Then follows a discussion on the need of parallax correction and so on.

The Diameters of the Sun and the Moon and their Distances from the Earth

For the calculations of the shadows cast either by the earth or the moon it is necessary to know the diameters of the discs of the sun and the moon, the earth's diameter and the distances of the sun and the moon from the earth. Different astronomical texts give different values of these elements, some of which are summarized in Table 2.5.

The ratio of diameter to distance gives the angular diameter of the sun or the moon in radians. It is to be noted that the angular diameters of the sun and the moon are nearly the same and agree approximately with the modern values. To obtain the angular diameters in minutes, the above-mentioned ratios are directed in Hindu astronomical texts to be multiplied by R (= 3438′) which is the equivalent in minutes of one radian. Taking Bhāskara II's figures, the mean angular diameters of the sun and the moon work out to 32·5′ and 32′ respectively.

The values of the diameters of the sun and the moon, given above, are those for their mean orbits and therefore require to be corrected due to their motions in eccentric circles. This correction is done by multiplying the mean diameters by the ratio of the true daily motion to the mean daily motion. Thus, if v'_s and v_s be the true and mean daily motions of the sun, v'_m and v_m those for the moon, d'_s and d_s be the true and mean diameters of the sun and d'_m and d_m those for the moon, the following relations are to be applied:[a]

$$d'_s = d_s \cdot \frac{v'_s}{v_s}$$

$$d'_m = d_m \cdot \frac{v'_m}{v_m}.$$

Calculation of the Length and the Diameter of the Earth's Shadow

Āryabhaṭa I and followers of the Āryabhaṭa school (Bhāskara I and others) give the following simple rule for the length of the shadow (measured from the earth to the tip of the umbral cone) and the diameter of the shadow at the mean orbit of the moon as follows:

$$\text{Length of the earth's shadow} = \frac{\text{sun's distance} \times \text{earth's diameter}}{\text{sun's diameter} - \text{earth's diameter}}.$$

[a] *Sū. Si.*, iv. 2.

TABLE 2.5

Diameters of the sun, the moon and the earth, distances of the sun and the moon from the earth

	Sun			Moon			Earth's diameter (in *yojana*)
	Diameter (in *yojana*)	Distance (in *yojana*)	Diameter / Distance	Diameter (in *yojana*)	Distance (in *yojana*)	Diameter / Distance	
Āryabhaṭa I, Bhāskara I ..	4,410	459,585	0·009596	315	34,377	0·009163	1,050
Bhāskara II	6,522	689,377	0·009461	480	51,566	0·009308	1,581
Sūrya-siddhānta	6,500	689,378	0·009429	480	51,566	0·009309	1,600
Modern values (in miles) ..	86,400	92,900,000	0·0093	2,160	238,900	0·009	7,926·70 (equatorial) 7,900·02 (polar)

Diameter of shadow at moon's orbit $= \dfrac{\text{(length of earth's shadow}-\text{moon's distance)} \times \text{earth's diameter}}{\text{length of earth's shadow}}$.

The above results follow easily from the construction given in Fig. 2.8. S, E and M indicate the positions of the sun, the earth and the moon as also their centres.

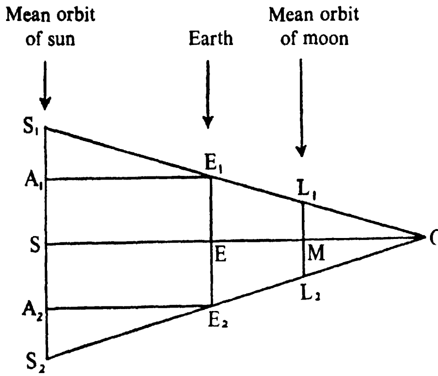


FIG. 2.8. Earth's shadow.

S_1S_2 = diameter of the sun—d_s

E_1E_2 = diameter of the earth—d_e

ES = distance of the sun from the earth—R_s

EM = distance of the moon from earth —R_m

OE = length of earth's shadow—L

L_1L_2 = diameter of shadow at moon's orbit—S

Now,

$$\frac{EO}{A_1E_1} = \frac{EE_1}{A_1S_1} = \frac{EE_2}{A_2S_2} = \frac{EE_1+EE_2}{A_1S_1+A_2S_2} = \frac{E_1E_2}{S_1S_2-A_1A_2} = \frac{E_1E_2}{S_1S_2-E_1E_2}$$

$$\therefore \quad EO = \frac{ES.E_1E_2}{S_1S_2-E_1E_2}; \text{ or } L = \frac{R_s.d_e}{d_s-d_e}. \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

Again,
$$\frac{L_1L_2}{E_1E_2} = \frac{OM}{OE} = \frac{OE-EM}{OE}$$

$$\therefore \quad L_1L_2 = \frac{E_1E_2(OE-EM)}{OE}$$

or
$$S = \frac{d_e(L-R_m)}{L}. \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

Proceeding further,
$$S = d_e - \frac{d_eR_m}{L}.$$

Substituting from (1),
$$S = d_e - \frac{d_eR_m(d_s-d_e)}{R_sd_e}$$

or
$$S = d_e-(d_s-d_e)\frac{R_m}{R_s}. \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

Conditions of Eclipse

Let us now consider the situation at a lunar eclipse. The earth's shadow and the moon about to enter it will both be near the node, the

point of intersection between the ecliptic and the moon's orbit. In Fig. 2.9, ON is the ecliptic, MN the moon's orbit, N the node, O the centre of the shadow of diameter S_1S_2 and M the centre of the moon's disc of diameter M_1M_2.

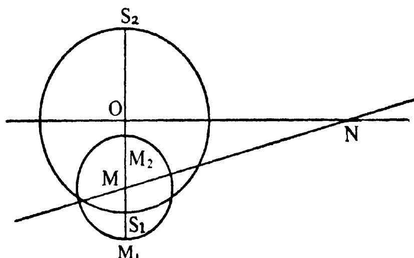


FIG. 2.9.

Let S = diameter of shadow,
d_m = diameter of moon,
$\beta = OM$ = latitude of moon.

Then S_1M_2, e.g. the part of the moon eclipsed, is given by

$$S_1M_2 = OS_1 - OM_2 = OS_1 + MM_2 - OM = \tfrac{1}{2}(S+d_m) - \beta.$$

This relation is given in the *Sūrya-siddhānta*[a] which further says:

a lunar eclipse will take place if $\tfrac{1}{2}(S+d_m) > \beta$;
a total lunar eclipse will take place if $\tfrac{1}{2}(S+d_m) - \beta > d_m$;
or $\tfrac{1}{2}(S-d_m) > \beta$;
and a partial lunar eclipse will take place if $\tfrac{1}{2}(S+d_m) - \beta < d_m$;
or $\tfrac{1}{2}(S-d_m) < \beta < \tfrac{1}{2}(S+d_m)$.

Duration of the Eclipse

It is now possible to calculate the duration of an eclipse and derive a simple relation for such duration.

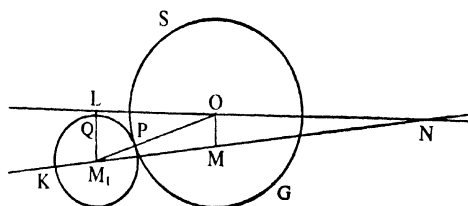


FIG. 2.10. Duration of eclipse.

In Fig. 2.10,

LON—ecliptic;
KM_1MN—moon's path meeting the ecliptic at the ascending node N;
SPG—earth's shadow;
KQP—moon's disc touching the shadow at P and about to be eclipsed;
OP—semi-diameter of shadow $= S/2$;
M_1P—semi-diameter of moon's disc $= \dfrac{d_m}{2}$;

[a] *Sū. Si.*, iv. 10.11.

$LM_1 = OM =$ latitude of moon $= \beta$; during the progress of the eclipse the latitude is assumed to remain constant as an approximation and for simplicity of calculation.

Then $OL = MM_1 = \sqrt{OM_1^2 - OM^2}$, assuming $LOMM_1$ to be a rectangle,

$$= \sqrt{\left(\frac{S+d_m}{2}\right)^2 - \beta^2}.$$

Let $v_s - v_m$ be the relative diurnal motion of the moon with respect to the sun (or its shadow) and t_s half the time of duration from first to last contact, called *sthityardha* in Hindu astronomy. Then

$$t_s = \frac{OL}{v_s - v_m} = \frac{1}{v_s - v_m}\sqrt{\left(\frac{S+d_m}{2}\right)^2 - \beta^2} \text{ day} = \frac{60}{v_s - v_m}\sqrt{\left(\frac{S+d_m}{2}\right)^2 - \beta^2}$$

ghaṭikās or *nāḍis*.

In the same way, t_v, half the time of total obscuration, called *vimardārdha*, is calculated from the following expression:

$$t_v = \frac{60}{v_s - v_m}\sqrt{\left(\frac{S-d_m}{2}\right)^2 - \beta^2} \text{ ghaṭikās or nāḍis}$$

The above relations also hold good for solar eclipse in which the diameter of the sun's disc is to be substituted for that of the earth's shadow, and the latitude is corrected for parallax.

Parallax

The solar eclipse is complicated by the phenomenon of parallax. The sun and the moon will be in conjunction with respect to the earth when these bodies and the centre of the earth lie in the same straight line. To an observer on the horizon at the same time, this will not be so (except when the sun and the moon are at the zenith), because both the sun and the moon will appear differently depressed on account of their unequal distances from the earth. The angle made by the two straight lines joining the body to the centre of the earth and the observer on its surface is the geocentric parallax of that body. Thus $\angle OMC$ and $\angle OSC$ are the geocentric parallaxes respectively of the moon at M and the sun at S (Fig. 2.11). For the horizontal positions of the sun and the moon when their zenith distances are 90°, the respective geocentric parallax is called the horizontal parallax ($\angle OM_HC$, $\angle OS_HC$). The peculiarity of the Hindu astronomers was that they did not deal with the absolute parallaxes

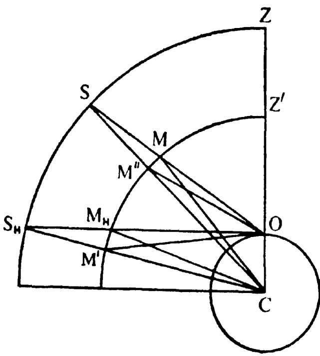


FIG. 2.11.

of the sun and the moon, but considered only their differences, that is the $\angle MCM''$ in the first and $\angle M_H CM'$ in the second case, which was sufficient for eclipse calculations. Moreover, they made use of parallax only in connection with the eclipse calculations, but did not apply it for other astronomical purposes.

If for the position M of the moon, the zenith distance $\angle MOZ'$ be z, radius of the earth be r and the distance of M from the centre of the earth C be R, then geocentric parallax p is given by

$$\sin p = \frac{r}{R} \sin z$$

$$\text{or} \qquad p = \frac{r}{R} \sin z, \text{ since } p \text{ is very small.}$$

For $z = 90°$, p = horizontal parallax, $p_0 = r/R$, so that

$$p = p_0 \sin z \quad .. \quad .. \quad .. \quad .. \quad (1)$$

This sinusoidal relationship is implied in all Hindu treatment of parallax as we shall presently see.

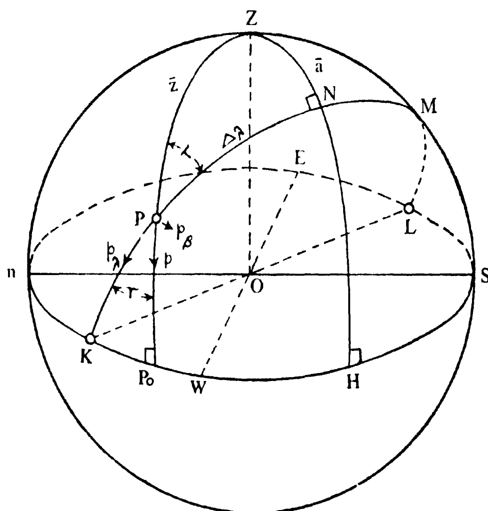


FIG. 2.12 Latitudinal and longitudinal parallax.

In Hindu astronomical works the horizontal parallax of the moon or the sun is given as $\frac{1}{15}$ of their daily motion. For the moon it is 52′ 42″ and for the sun 3′ 56″, making their horizontal parallax difference equal to 48′ 46″ or 4 *ghaṭikās* (fifteenth part of a day) in time.

For eclipse calculations, it is necessary to resolve the geocentric parallax into two components, one in the direction of the ecliptic, called the longitudinal component, and another at right angles to the ecliptic, called the

latitudinal component. The treatment given here is based on one due to O. Neugebauer.[a]

ELSWn—horizon of the observer *E*, *S*, *W*, *n* being the east, south, etc., points;
nZMS—meridian;
KPNML—ecliptic;
N—nonagesimal, that is the point of the ecliptic nearest the zenith; *tribhona lagna* or *tribhona* (i.e. *lagna* = 3 *rāśi*);
M—culminating or the ecliptic point meeting the meridian; this is called the *madhya lagna*;
L—rising point of the ecliptic, called the *udaya lagna*;
EL—amplitude of the rising point, *udaya*;
P—the body on the ecliptic whose geocentric parallax p is to be resolved;
p_λ, p_β = longitudinal and latitudinal components of parallax p respectively;
ZNH, ZPP_0—secondaries to the horizon through *N* and *P* respectively;
ZN—zenith distance of the nonagesimal, *dṛkṣepa* $= \bar{a}$;
NH—altitude of the nonagesimal, *dṛggati* $= a = (90-\bar{a})$;
ZP—zenith distance of the body $P = \bar{z}$;
PP_0—altitude distance of the body $P = z = (90°-\bar{z})$;
PN—longitude difference between the nonagesimal *N* and $P = \Delta\lambda$;
KP—longitude difference between *K* and $P = \overline{\Delta\lambda} = (90-\Delta\lambda)$;
$KPP_0 = ZPN = \gamma$.

Now $$p_\beta = p \sin\gamma \quad \ldots \quad (2.1)$$

$$p_\lambda = p \cos\gamma \quad \ldots \quad (2.2)$$

and $$p = p_0 \sin\bar{z}$$

where p_0 = horizontal parallax and from relation given above (1).
From the spherical triangle *ZPN*,

$$\frac{\sin\gamma}{\sin\bar{a}} = \frac{\sin 90}{\sin\bar{z}}\,; \quad \sin\gamma = \frac{\sin\bar{a}}{\sin\bar{z}}.$$

From (2.1) and (1),

$$p_\beta = p\sin\gamma = \frac{p\sin\bar{a}\,.\,p_0}{p} = p_0\sin\bar{a}. \quad \ldots \quad (3)$$

If the rectangle formed by the components p_λ and p_β be considered plane,

$$p_\lambda^2 = p^2 - p_\beta^2 = (p_0\sin\bar{z})^2 - (p_0\sin\bar{a})^2 = p_0^2(\sin^2\bar{z} - \sin^2\bar{a})$$

$$= p_0^2(\sin^2 a - \sin^2 z). \quad \ldots \quad (4)$$

From the spherical triangle, KPP_0, and keeping in mind that P_0, *H* are right angles and *KN*, *KH* are quadrants,

[a] Neugebauer (2), pp. 122–24.

$$\frac{\sin PKP_0}{\sin PP_0}=\frac{\sin 90}{\sin PK}; \quad \frac{\sin NH}{\sin PP_0}=\frac{\sin 90}{\sin PK};$$

$$\frac{\sin a}{\sin z}=\frac{1}{\sin \overline{\Delta\lambda}}; \quad \sin z=\sin a \sin \overline{\Delta\lambda}. \quad .. \quad (5)$$

Combining (4) and (5),

$$p_\lambda^2=p_0^2(\sin^2 a-\sin^2 a \sin^2 \overline{\Delta\lambda})$$

$$=p_0^2 \sin^2 a(1-\sin^2(90-\Delta\lambda))$$

$$=p_0^2 \sin^2 a \sin^2 \Delta\lambda$$

$$\text{or} \quad p_\lambda=p_0 \sin a \sin \Delta\lambda. \quad .. \quad .. \quad .. \quad .. \quad (6)$$

To express (6) in the form usually given in Hindu astronomical texts,

$$p_\lambda=\frac{p_0}{R^2}\cdot R\sin a.\ R\sin \Delta\lambda=\frac{4 \text{ Sin } a \text{ Sin } \Delta\lambda}{R^2} \quad .. \quad (7)$$

because $p_0 = 4$ *ghaṭikās*; $R \sin a = \text{Sin } a$; $R \sin \Delta\lambda = \text{Sin } \Delta\lambda$

$$\text{or } p_\lambda=\frac{\text{Sin } \Delta\lambda}{\left[\frac{R^2}{4 \text{ Sin } a}\right]}. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (7.1)$$

The expression $\left[\frac{R^2}{4 \text{ Sin } a}\right]$ is called *cheda* (divisor). Thus *cheda* is defined in the *Sūrya-siddhānta* as follows: '. . . the square of the sine of one sign (30°) divided by the *dṛggatijīva* (sine of altitude of the nonagesimal) yields the *cheda*'.[a] The equation (7.1) is stated in the next rule as follows: 'The sine of the interval between the nonagesimal and the sun is to be divided by this *cheda*; the quotient is the parallax in longitude of the sun and the moon eastward or westward, in *nāḍis*.'

Thus to calculate p_λ, it is important to know Sin a, for which detailed methods are given in the texts.

ASTRONOMICAL INSTRUMENTS

Several types of simple astronomical instruments were in use among astronomers in India in ancient and medieval times. Some of these instruments have been variously described in the astronomical *saṃhitās* and *siddhāntas*. These instruments include water clocks, gnomon, staff, arc, wheel and the armillary sphere.

The Water Clock or Clepsydra

The use of water clocks is referred to in the *Vedāṅga Jyotiṣa*. The earliest type probably consisted of a simple vessel having a small orifice at its bottom, permitting water to flow out in a fixed unit of time, say a *nāḍikā*. In course of time the water-flowing type gave place to the sinking

[a] *Sū. Si.*, iv, 7.

type in which a metal vessel with a hole was permitted to sink in a larger vessel containing water. The *Sūrya-siddhānta* describes such a sinking type clepsydra which is 'a hemispherical copper vessel, with a hole in the bottom, set in a basin of pure water, sinking sixty times in a day and night'. Descriptions of similar water clocks are met with in the works of Brahmagupta, Lalla, Bhāskara II and others. We know from I-Hsing's account that water clocks were indispensable in Buddhist monasteries, and skilled mechanics used to be maintained by the king for their upkeep.

The Gnomon (Śaṅku)

In its simplest form it is a vertical rod with 12 divisions. It is mentioned in the *Atharvaveda* and some of the *Brāhmaṇas*. The *Śulba-sūtras* mention the use of the gnomon for the determination of cardinal points. Its description as well as details of its use in astronomy are given by Varāhamihira in his *Pañcasiddhāntikā*, by Bhāskara I, Brahmagupta, Lalla and Bhāskara II. 'Take for a gnomon a cylindrical piece of ivory', writes Bhāskara II, 'and let it be turned on a lathe, taking care that the circumference is equal above and below; its shadows will enable the determination of the points of the compass, the observer's place, its latitude, etc., and the time.'

The Cakra or Circle

It is a circle of which the circumference is divided into 360 degrees. Provided with an axis at the centre perpendicular to its plane and suspended with a string, the circle was used for finding zenith distances and longitudes. Brahmagupta and Lalla mention an instrument called *pīṭha* which is also a circle with an upward staff attached to it. Bhāskara II describes a versatile *phalaka yantra* which is essentially a circle or *cakra* which possibly served the purpose of an astrolabe.

Cāpa, Dhanu, Kartari, Turīya

The *cāpa* is a half circle; *dhanu* is an arc; *kartari* is also a type of arc instrument; *turīya* is a quadrant. The first one is mentioned by Bhāskara II, the second type is mentioned by Brahmagupta and Bhāskara II, the third type is referred to in the *Śiṣyadhīvṛddhida* and so on. The word *turīya* is mentioned in the *Ṛgveda* in connection with the description of an eclipse, but it is doubtful if the word had anything to do with a quadrant.

The Armillary Sphere (Gola Yantra)

This is really a wooden model of the celestial sphere showing the various great circles used in astronomy. The model *gola yantra* was used mainly for purposes of demonstration. The outer sphere called *khagola* (the celestial sphere) has a polar axis called *dhruvayaṣṭi*. The sphere consists of a number of great circles to represent the horizon, the meridian, the

equinoctial, the prime vertical, the 6 o'clock circle and so on. The altitude or the azimuth of any star is indicated by a movable altitude-azimuth circle. The horizon is divided into degrees counted either from the east-west points or the north-south points. Inside the *khagola* is fixed another sphere, the *bhagola*, on which are represented the ecliptic, the lunar and planetary orbits called the *kṣepa-vṛttas*, the declination and diurnal circles. This can be made to revolve round a polar axis. In the same manner there is a third sphere, the *dṛggola*, which is supported on the axis of the *khagola* produced. The whole arrangement of the armillary sphere is such that the *khagola* and *dṛggola* remain fixed while the innermost *bhagola* alone can be made to revolve.

There is a good description of an armillary sphere in the *Sūrya-siddhānta*, the *Siddhānta-śiromaṇi* and several other astronomical texts, which clearly shows the care and pains taken by the Hindu astronomers in elucidating the principles of spherical astronomy to those who wanted to master the science of the heavens.

Astronomical Instruments of Jai Sing's Observatories

We have already noticed Sawāi Jai Sing's efforts in developing observational astronomy in India towards the end of the seventeenth and the beginning of the eighteenth century. Jai Sing used both metal instruments such as then were in vogue among Muhammadan astronomers and massive masonry instruments of his own design and construction.

The Astrolabe

Among the metal instruments, the astrolabe naturally occupied the most important place. This versatile instrument although known to the Greeks was perfected by the Islamic astronomers in West Asia, Central Asia and Spain and travelled to India along with Arab astronomy. The Jaipur collection includes an astrolabe dated the 31st year of the reign of Shāh Jāhan and a Zarqālī astrolabe dated the 23rd year of the reign of Aurangzeb. Such astrolabes have also been found in other places in India, some of which are at present preserved in a number of Indian museums and libraries. Most of them are engraved in Persian characters, but a few engraved in *Nāgarī* characters have also come down to us. Among the medieval astrolabe-makers in India we hear of Zia'u'd-din Muhammad, son of Qâ'im Muhammad, son of Mullā Isā, son of Sheykh Allāh-Dād.[a] A number of astrolabes in which his name is engraved have been preserved. The family worked in Lahore. Zia'u'd-din was a skilled astrolabe-maker; his father Qâ'im and grandfather Allāh-Dād were skilled mechanics, proficient in the making of globes and astronomical instruments.

Astrolabes (Arabic *Aṣṭurlāb*) are of three types, e.g. the spherical, the flat and the rod. Of them the flat type representing the projection of the celestial sphere on a plane is the most popular. Also known by the

[a] Nadri, pp. 621–31.

name of 'planisphearum', it is a small portable metal disc instrument, of which the diameter varies from about 4″ to 8″ (Fig. 2.13(*a*)). The instrument consists of a disc, called the 'mother' or *umm*, provided with a raised rim graduated in 360 degrees. The inner front surface, the 'face', is called the *wadjih* and the outer back surface the *ẓahar*. Within the inner front surface of the 'mother' are set a number of circular tablets called *ṣufā'iḥ*. The circular tablets are generally nine in number and are marked with circles parallel to the horizon, projections of vertical circles, equator, etc.

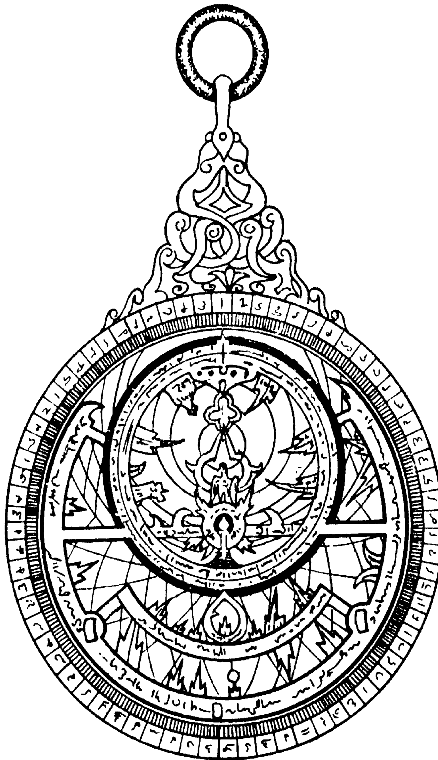


FIG. 2.13(*a*). Astrolabe. The 'face', *wadjih*, showing the graduated rim, the 'spider' and the circular tablets as seen through the 'spider'.

In the 'mother' immediately above the circular tablets is set the most conspicuous part of the astrolabe, e.g. the 'spider' or 'aranea', Arabic *'ankabūt* or *shabaka*. The 'spider' (Fig. 2.13(*b*)) is an open circular structure so designed that the circular tablets below can be easily seen through. It consists of an eccentric circle, the ecliptic, of which the rim is divided into 12 parts, each bearing the name of a zodiacal sign. A number of pointed metal strips artistically cut project inside from the rims of the centric and



FIG. 2.13(*b*). Astrolabe. The 'spider' or *'ankabūt.*

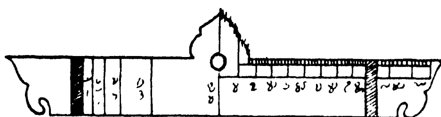


FIG. 2.13(*c*). Astrolabe. The diopter or *al-'iḍāde.*

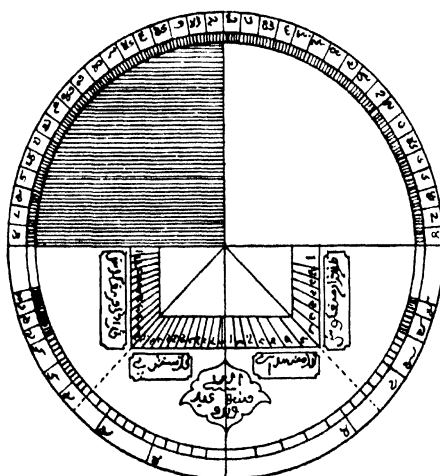


FIG. 2.13(*d*). Astrolabe. The 'back', *ẓahar.*

the eccentric circles. Each strip bears the name of a bright star. The fine points of the ornamental metal projections are called indicators, *shaẓīyā*. The 'spider' is capable of rotation round the central pivot. With the help of several circular tablets, the 'spider' enables the user to find the longitudes and latitudes of stars, the hour of day or night from the observed altitude of the sun or the stars and so on.

On the back of the astrolabe there is a revolving piece called the diopter or *al-'iḍāde* (Fig. 2.13(*c*)). It is a ruler of length equal to the diameter of the circular back, each end being sharpened to a point and containing a hole through which the sun's rays pass or the stars can be sighted. The two arms of the ruler are graduated but differently. The *al-'iḍāde* revolves round an axis passing through the centres of all the various pieces held together by a bolt and a screw at either end of the axis. The back of the astrolabe is divided into four quadrants (Fig. 2.13(*d*)). The rim of each of the two upper quadrants is graduated in degrees at intervals of 5°. One of them is marked by a set of equidistant parallel lines dividing the vertical radius into 60 equal parts; these are called lines of sines from which the sines are read off. Other quadrant contains a number of declination circles. The lower quadrants contain circular scales and rectangular markings for shadow measurements with a gnomon fitted in the centre. In other designs, the back is provided with a number of concentric circles and chronological indications forming a sort of perpetual calendar.[a]

Masonry Instruments

Masonry instruments built under Jai Sing's instructions to equip the observatories at Jaipur, Delhi and other places include huge dials, azimuth instruments, meridian circles, sextants and several variations of them. Of the huge dials designed by Jai Sing himself, the most important was the equinoctial dial called *samrāṭ yantra* (Fig. 2.14). It is a right triangular gnomon *ABC* with its hypotenuse *AB* parallel to the earth's axis; to the gnomon is attached

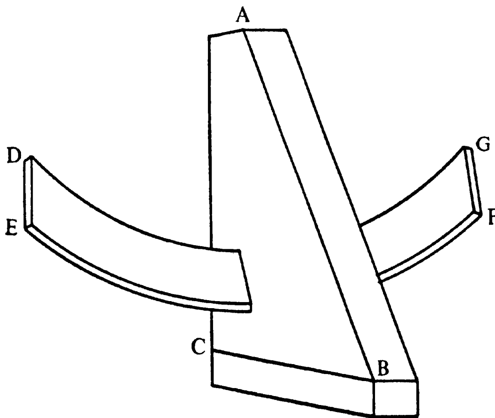


FIG. 2.14. *Samrāṭ yantra.*

[a] Khareghat, pp. 152–157.

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a quadrant circle *DEFG* parallel to the plane of the equator. Each edge of the quadrant is graduated in hours and minutes, as also in degrees. The gnomon itself is provided with tangent scales.

Jai prakāś is a hollow hemispherical dial provided on its concave face with a number of coordinates. The edge of the hemisphere represents the horizon. Cross-wires are stretched along north-south and east-west directions. Only Delhi and Jaipur observatories are fitted with a *jai prakāś* dial; the diameter of the instrument at Delhi is 27′ 5″ and that at Jaipur 17′ 10″.

Rāmyantra is a cylindrical instrument which is open at the top and has a central pillar. The inside circular wall and the floor are graduated. The floor and the wall are broken up into a number of sectors to facilitate observations. Wall sections are provided with notches in which sighting bars can be fitted horizontally. Hunter compared it with a kind of cylindrical astrolabe referred to by al-Bīrūnī. This is also an instrument characteristic of Delhi and Jaipur observatories.

Other instruments comprise the *digaṃśa yantra* which is a large circular protractor. It consists of a central pillar 4′ high surrounded by an inner wall of the same height and an outer wall of double the height of the former. Both walls are graduated. The instrument is used for azimuth observations. The *nāḍivalaya yantra* is a circular dial, the *dakṣiṇavṛtti yantra* is a meridian circle, the *ṣaṣṭāṃśa yantra* is a graduated meridional arc, and the *rāśi valaya* is a set of 12 dials for use in connection with the rising signs of the zodiac from which the sun's longitudes can be determined.

INTERRELATIONSHIP BETWEEN INDIAN, GREEK, CHINESE AND ARABIC ASTRONOMY

India, owing to her pre-eminent geographical position, was always a meeting-place of many nations and cultures. This enabled her from the very beginning to play an important role in the transmission and diffusion of ideas. Needless to say, it was a two-way traffic in the course of which her own ideas and achievements in religion, science, arts and literature travelled abroad with as much facility as those of her neighbouring and far-flung nations flowed into her own borders to cross-fertilize her very same endeavours. Her cultural and commercial contacts with West Asia and Egypt extended to prehistoric times. In historic times, the Achaemenian Empire and the Graeco-Bactrian kingdoms provided an effective bridge between India at one end and West Asia and the Mediterranean world at the other. Ptolemaic Egypt and Rome's Eastern Empire developed a thriving commercial and trade relations with India. After the spread of Buddhism into China, India, naturally enough, became the place of pilgrimage of Chinese Buddhists, and in this way was opened up a Sino-Indian intercourse in scientific and cultural exchanges which lasted

PLATE I



A Thirteenth Century Astrolabe, Archaeological Museum, Red Fort, Delhi. (Courtesy, Archaeological Survey of India, New Delhi.) *See* pp. 126 ff.

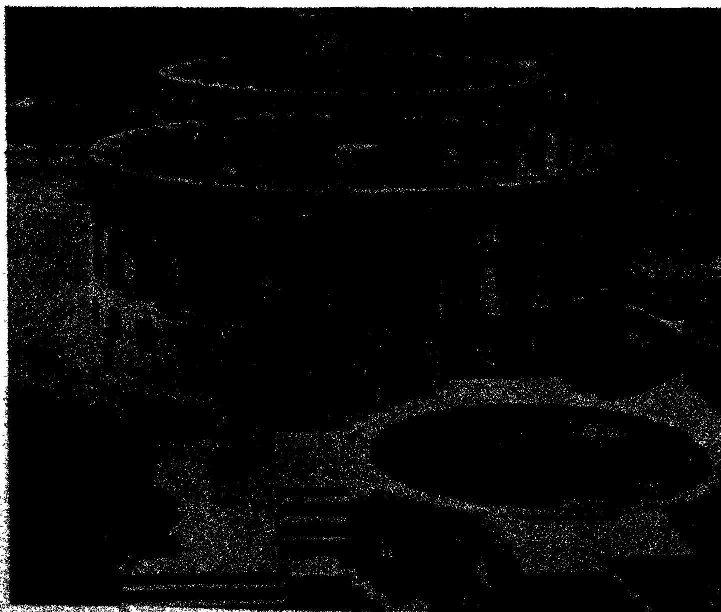


The Samrāṭ Yantra, Yantar Mantar, Delhi. (Courtesy, Archaeological Survey of India, New Delhi.) *See* p. 129

PLATE II



The Miśra Yantra, Yantar Mantar, Delhi. (Courtesy, Archaeological Survey of India, New Delhi.) *See* p. 130



The Rām Yantra and the Jai Prakāś (right-hand corner below), Yantar Mantar, Delhi. (Courtesy, Archaeological Survey of India, New Delhi.) *See* p. 130

for several centuries. The opening up of 'silk-roads' and the consequent flow of trade and commerce through Central Asia also contributed to the process of such exchanges. The rise of Islam witnessed a new interest in India and in her savants. In spanning the world from Spain to South-East Asia and establishing her political and commercial supremacy over half of the old world, Islam acted as the natural carriers of ancient knowledge as cultivated among various peoples and, in the process, helped in the preservation and further development of that knowledge affecting India in no small way.

Against the above historical background it is futile to hold extreme views such as that Indian astronomy was wholly of indigenous development or that it was derived wholly from a foreign source. This is true not only of India but of all cultures to a greater or less degree, for, in the development of knowledge, each culture, marked as it was by its own genius and individuality, depended heavily on the efforts of others.

Much of the Vedic astronomy, as we have seen, was of a primitive nature capable of independent development wherever an agrarian civilization took root. Its only important sophistication was the development of a stellar zodiac, the *nakṣatra* system, to follow the motions of the moon and the sun. Such a system also characterized the early primitive astronomy of contemporaneous civilizations in China and West Asia. This occasioned a controversy as to whether the Indian *nakṣatra*, the Chinese *hsiu*, the Babylonian lunar mansions or the Arab *manāzil* originated independently, if not, whether any of them having the pride of priority influenced the development of all the rest, or whether each of them had a common origin. This question of origin has, however, still remained an unsolved problem. In the meantime, the *nakṣatras* fortified by the high antiquity of the *Ṛgveda* and the *Yajurveda* texts in which these were first mentioned, by the fixity of their number (27 or 28), and by their consistent use as a stellar framework in calendrical astronomy, maintained their characteristic position in Indian pre-scientific astronomy.

INFLUENCE OF BABYLONIAN AND GREEK ASTRONOMY

The position is different when we come to Indian astronomy of the *Siddhāntic* period. Although records bearing on this transitional phase of Indian astronomy are very scanty, what we know clearly seems to indicate unmistakable foreign influence. Such a conclusion of foreign, e.g. Greek and Babylonian, influence is based on eulogistic references to Greek astronomy and astronomers, transliteration into Sanskrit of Greek technical terms and principles and methods typical of Greek astronomy, the historical development of which is untraceable in earlier Sanskrit literature.

Garga and Varāhamihira have referred to the proficiencies of the Greeks (*yavanas*) in astronomy and even stated that although they were *mlecchas* they should be honoured as *ṛṣis*. As to the use of Greek technical

words, Varāhamihira in his *Bṛhajjātaka* gives the names of the zodiacal signs as follows: *Kṛiya* (*Meṣa*), *Tāvuri* (*Bṛṣa*), *Jituma* (*Mithuna*), *Leya* (*Siṃha*), *Kulīra* (*Karkaṭa*), *Pāthona* (*Kanyā*), *Jūka* (*Tulā*), *Kaurpya* (*Vṛścika*), *Taukṣika* (*Dhanu*), *Ākokera* (*Makara*), *Hṛdroga* (*Kumbha*) and *Ittha* (*Mīna*). Other examples are *liptā*, minutes; *horā*, hour, horoscope; *dreṣkāṇa* or *dṛkkāna*, decan; *āpoklima*, inclination; *kendra*, anomaly; *jyāmitra*, chord (lit. lover of chord), etc. These and other technical terms were used in the same sense by Paulus Alexandrinus (*c.* A.D. 378), the author of *Eisagoge*, an astrological work.

As to astronomical parameters, principles and methods of foreign origin which found their place in the Indian system, Varāha's *Pañca-siddhāntikā* throws some light. Pradyumna and Vijayanandin who flourished before Āryabhaṭa I made a special study of the superior and inferior planets and probably had access to Babylonian sources. P. C. Sengupta suggested that Babylonian elements thus transmitted to India were developed into a fuller planetary theory by Āryabhaṭa I who did very much the same thing for Indian astronomy as Ptolemy had done for the Greek. Further evidence of Babylonian influence is provided by the computation of lunar motions as given in the *Vaśiṣṭha-siddhānta*. This text yields the value of the anomalistic month as 27; 33, 16, 22 . . . in sexagesimal unit, which is in remarkable agreement with the Babylonian value of 27; 33, 16, 26, 54. It is very likely that the convergents of the anomalistic month, e.g. $\frac{248}{9}$ and $\frac{3031}{110}$, discovered in a tablet from Uruk and discussed by Schnabel, were known to the author of the *Vaśiṣṭha-siddhānta*. Recently David Pingree drew attention to an astrological text, the *Yavanajātaka* of Sphuji-dhvaja (A.D. 269), which contained the use of Babylonian linear methods in planetary calculations.

The *Romaka*- and the *Pauliśa-siddhānta*, of which the very titles indicate foreign origin, were long taken to represent Greek or Alexandrian-Greek astronomy. Although already indianized, the *Romaka* was still using the Metonic cycle and the period followed by the *Pauliśa* was different from the *yuga* of later Hindu astronomers. In one of them the *ahargaṇa* is calculated for the meridian of Yavanapura, and in the other the difference in the longitudes of Yavanapura and Ujjayinī is expressly given. With regard to other elements of astronomy discussed in these works, similarities with those of the Greek astronomy were noticed, which led Thibaut to observe: '. . . it certainly appears highly probable that the *Pauliśa*- and *Romaka-siddhāntas* were the earliest Sanskrit works in which the new knowledge imported from the West was embodied.' Be that as it may, even the earliest account of these works as preserved by Varāha clearly shows significant modifications. In mathematical computations the Greek chords were replaced by the half-chords, i.e. sine functions, and convenient tables were constructed accordingly. In the planetary theories, although the geometrical models were adopted, the longitudes of apogee, the sizes of the epicycles and other related parameters were different, agreeing in many cases more closely with observations.

INDIAN ASTRONOMY IN CHINA

Sino-Indian religious and cultural intercourse which might have started about the beginning of the Christian era became really intensified from the time of Yueh-Chih Dharmarakṣa (third-fourth century A.D.) and the Kashmirian Kumārajīva (fourth-fifth century A.D.) who visited China by the overland Central Asian route. During the following centuries a steady stream of Buddhist scholars from Kashmir, Western, Central and Eastern India visited China to carry out their missionary activity. Their main activity was no doubt confined to preaching the Buddhist doctrines and translating canonical texts, but some of them doubtless were engaged in spreading secular learning such as astronomy, mathematics and medicine. In the catalogue of the Sui dynasty (A.D. 610) are mentioned a number of Brahminical works on astronomy, of which some are enumerated below:

(1) *Po-lo-mên t'ien-wen-ching*—Brahminical astronomy, in 21 books;
(2) *Po-lo-mên chieh-chieh hsien-jên-wen-shuo*—Astronomical dissertations of the Brāhmaṇa Chieh-chieh, in 30 books;
(3) *Po-lo-mên t'ien-wen*—Brahminical astronomy, in 1 book;
(4) *Po-lo-mên yin yang Suan ching*—Brahminical method of calculating time, in 1 book.

Nothing is known about the contents of these works, but the very titles and their careful listing in a dynastic catalogue clearly indicate an interest in Indian astronomy among the Chinese scholars in the beginning of the seventh and possibly in the sixth century A.D. In the seventh century again we hear of an Astronomical Board at Chang-Nan where Indian *siddhāntas* bearing the names of *Gautama*, *Kāśyapa* and *Kumāra* used to be taught. The Thang dynasty records mention astronomers bearing the name 'Ch'u-t'an' which is the Chinese transcription of the Indian name 'Gautama'. Ch'u-t'an Hsi-ta (meaning Gautama Siddha or Siddhārtha), an astronomer in the Thang Court (eighth century A.D.), translated an Indian calendar under the Chinese title *Chiu-Chi-li*. The *navagraha* or the astronomy of 9 planets, the *Rāhu-Ketu* theory of eclipse and other peculiarities of Hindu astronomy began to appear in the Chinese astronomical literature from about this time. Its influence can be somewhat guessed from the fact that I-hsing, a noted Tantric-Buddhist astronomer of the Thang period, was asked by the emperor to study the principles of Indian astronomy and mathematics introduced to China by Hsi-ta and other scholars.

INDIAN ASTRONOMY AMONG THE ARABS AND IN LATIN EUROPE

Astronomy among the Arabs at the time of their embracing Islam was rather in a primitive state. They had some practical knowledge of stars, the motions of the sun and the moon, which they utilized for purposes of reckoning time. Their interest in scientific astronomy was aroused

by the knowledge that the Hindus of India and the Persians of the Sassanian period had cultivated among themselves a better and more scientific system of astronomy indispensable for the making of accurate and reliable calendars. Ibn al-Adamī, in the preface of his astronomical tables *Naẓm al-iqd*, records the visit during the reign of Caliph al-Mansūr of an Indian astronomer who brought with him to the Caliph's court planetary tables, texts for the calculation of eclipses, ascension of signs and other matters of astronomical import. The astrologer Abu-Māshar of Balkh mentions an Indian astronomer from whom he derived the knowledge of the Hindu great cycle of 'Kalpa'. These visits and references doubtless proved useful, for very soon, under orders of al-Mansūr, Brahmagupta's *Brāhmasphuṭa-siddhānta* and *Khaṇḍakhādyaka* were translated into Arabic with the assistance of Hindu pandits, by Muhammad ibn Ibrāhīm al-Fazārī (*d.* 796 or 806) and Ya'qūb ibn Ṭāriq (*d.* 796). In the Arabic translations these works were known as *Sindhind* and *Arkand*.

About the same time al-Tamīmī translated the Pahlavi astronomical tables, the *Zīk-i Shatro-ayār*, into Arabic under the title *Zīj ashshahriyār*. This Persian work was compiled in the closing period of the Sassanian Empire and exerted considerable influence on the growth of the early phase of Arabic astronomical literature. We have it from al-Bīrūnī that the *Shatro-ayār* itself was based on Hindu astronomical methods of computation and parameters. In fact, Hindu astronomical texts were eagerly sought for, studied and translated into Arabic with a view to getting a better understanding of the Persian tables.

Kennedy, in his excellent survey of Islamic astronomical tables, has given an impressive list of such tables which were either translations of *siddhāntas* or based on methods and parameters contained in them. Some of these works include the Astronomical Tables of al-Khwārizmī (*c.* 840) revised later by Maslama al-Majrīṭī (*c.* 1000) of Spain, *Az-Zīj al-Mukhtari* of al-Ḥasan bin Miṣbāḥ (*c.* 870), *Az-Zīj al-Kabir* of an-Nairizi (*c.* 900), *Mukhtaṣar az-Zīj* of ibn aṣ-Ṣaffār (*c.* 1100). Some of the Arab astronomers like ibn Yunis and al-Battāni who followed Ptolemy in the compilation of their *Zījes* had access to the *Sindhind* and occasionally used Hindu parameters. In this transmission al-Bīrūnī (973–1048) played a distinctive role. Instead of directly translating the texts as al-Fazārī, ibn Ṭāriq and others did, he discussed Indian astronomy and astronomical methods critically in his *Ta'rikh al-Hind, al-Qānūn al-Ma'sūdī*, comparing and contrasting them with those of other systems. Interest in Hindu astronomy declined among the Eastern Arabs after they were acquainted with the works of Ptolemy, Theon of Alexandria and other Greek authors in their Arabic translations, but peculiarly enough Hindu astronomy and astronomical parameters continued to remain popular among the astronomers of Spain.

Some of the special features of Hindu astronomy which were in this way incorporated in Islamic *Zījes* are the zero meridian of Ujjayinī which assumed the name 'Arin', the era of *Kaliyuga* (February 17–18, 3102 B.C.)

which became the 'Era of Flood', the Hindu planetary theory, the tables of sine ($R = 150$), the tables of solar declinations, methods of spherical trigonometry, ascensional difference, calculation of parallax and its application to solar eclipse, etc.

The elements of Hindu astronomy passed into Latin Europe through Latin translations of some of the Islamic *Zījes* mentioned above. The most conspicuous of them is Adelard of Bath's (*c.* 1142) translation of al-Khwārizmī's astronomical tables in the version of the Spanish astronomer Maslama al-Majrīṭī. Another incomplete Latin translation of al-Khwārizmī's tables has been found in Corpus Christi College, Oxford, which has recently been edited, translated and commented upon by Neugebauer. In 1951, Lynn Thorndike published and translated an anonymous fifteenth-century Latin manuscript Ashmole 191 II, in which computations were made for the geographical latitude of Newminster, England, for the year 1428. The study of astronomical parameters and tables given in the unsuspecting manuscript has revealed the characteristic features of Hindu astronomy and another interesting instance of transmission as late as the fifteenth century possibly through Arabic (Spanish) intermediaries. The Newminster manuscript begins the Era of Flood from the year 3102 B.C. which is the beginning of the *Kaliyuga* era and uses the sine functions instead of the Greek chord, tabulating them for $R = 150$, a norm used in the *Khaṇḍakhādyaka* and in the Toledan Tables.

In this way Hindu astronomy itself modified by the elements of Babylonian and Greek astronomy travelled, through the powerful vehicle of Arabic language, as far west as England. The circuit was completed when, with the establishment of the Ghaznavid and the Mughal rule in India, the Greek or rather the more advanced Ptolemaic astronomy in Arabic version reached India and began to be studied and taught at first exclusively among the Muslim circles and gradually among select Hindu astronomers who appreciated its merit, its more refined mathematical techniques and observational standards.

3 MATHEMATICS

S. N. SEN

THE history of the development of mathematics in India is as old as the civilization of its people itself. It begins with the rudiments of metrology and computations in prehistoric times, of which some fragmentary evidence has survived to this day. The sacred literature of the Vedic Hindus—the *Saṃhitās*, the *Kalpasūtras* and the *Vedāṅgas*—contain enough materials, albeit scattered, to help form a good idea of the mathematical ability during the time of development of this class of literature. The *Śulba-sūtras* which form part of the *Kalpasūtras* are a veritable storehouse of information concerning enumeration, arithmetical operations, fractions, properties of rectilinear figures, the so-called Pythagorean Theorem, surds, irrational numbers, quadratic and indeterminate equations and related matters. The *Brāhmaṇas* and some *sūtras* contain interesting materials concerning progressive series, permutations and combinations.

Of the various religious sects that attained prominence in the closing phase of the Vedic period, the Jainas deserve special notice for their interest in, and cultivation of, mathematics. Their canonical literature lays great emphasis on mathematics and enumerates various topics such as number reckoning, fundamental operations, geometry, mensuration, fractions, equations, permutations and combinations. In some departments they made advances further than where the Vedic Hindus had left off.

Indian mathematics received a new lease of life during the first few centuries of the Christian era. The demands of astronomy, particularly the need for more accurate computations of planetary motions, eclipses, etc., were in no small measure responsible for this. From now on we meet with a succession of mathematicians and astronomers and a fairly steady growth of mathematical-astronomical literature. The mathematical contents of this literature and its voluminous commentaries have for obvious reasons occupied the greater part of the discussion in the following pages.

The medieval period witnessed the growth of a sizeable mathematical literature in Arabic and Persian and presented an opportunity for cross-fertilization of the efforts of two distinct cultures. How far that opportunity was seized has been discussed.

Situated at the cross-roads of many cultures, it was not given to Indian mathematics to develop in isolation. Although what happened in the most ancient times must remain a matter of speculation, records of late ancient and medieval times show that Indian mathematics stimulated mathematical endeavours abroad and itself received inspiration from neighbouring and distant culture areas. Such stimuli have been noticed even in the case of the complex and many-sided phenomenon of European Renaissance of the sixteenth century.

METROLOGY AND COMPUTATIONS IN PREHISTORIC TIMES

It is reasonable to believe that the builders of the Indus civilization developed a good degree of skill in their measuring and computational techniques. Without these it is difficult to comprehend their town-planning and architectural proficiencies and various other aspects of their civilization. As to metrology, we have the evidence of seals with pictographic inscriptions and numerous stone weights unearthed at Mohenjo-daro and Harappa. The pictographic inscriptions have not yet been deciphered, but by measuring the large number of weight specimens in modern units one can guess what their weight system possibly was. From the published masses of these weights, frequency charts have been constructed, which clearly show that these weights were intended to be fractions or multiples of the *uncia*.[a] Thus 288 specimens of small cubes of chert have been shown to fall under seven distinct groups. By assuming 1 *uncia* equal to 27·2 gm., these groups are as follows:

$\frac{1}{16}$ *uncia* = 1·7 gm.	1 *uncia* = 27·2 gm.
$\frac{1}{8}$,, = 3·4 ,,	2 ,, = 54·4 ,,
$\frac{1}{4}$,, = 6·8 ,,	5 ,, = 136 ,,
$\frac{1}{2}$,, = 13·6 ,,	

The discovery in large numbers from both the sites of the weight specimens of mass 13·6 gm. has led others to suggest this as the probable unit. The existence of a developed weighing system is further borne out by the discovery from these sites of the remains of quite a few metal scales used probably for weighing light and precious substances.

An interesting specimen of the Indus scale has come down to us among the finds from Mohenjo-daro in the form of the fragment of a shell measuring 6·62 cm. in

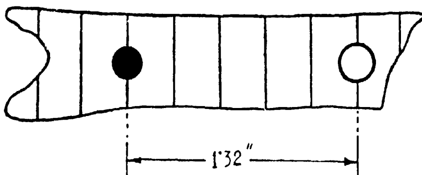


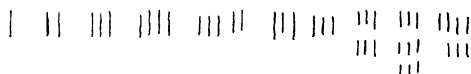
FIG. 3.1. Sketch of an Indus scale.

[a] Berriman, pp. 33–35.

length by 0·62 cm. The scale shows nine parallel lines cut with a fine saw. One of these lines is marked by a fine circle and the sixth line from it by a dot (Fig. 3.1). The measurement of these five intervals shows 1·32 inches making the distance between two consecutive lines equal to 0·264 inch. If the length between the circle and the dot can be called the Indus inch, as Berriman did, this becomes exactly equal to 2 Sumerian *shushi.* Another significance of the Indus scale is that 25 Indus inches equal 33 inches which again equal the yard prevalent throughout north India in Akbar's time.

Mackay[a] conjectured that the aforesaid scale was a part of the whole, probably 13·2 inches long, and hinted at a decimal mode of dividing and measuring lengths such as was characteristic of ancient Egypt and Elam. It is then easy to think that such a decimal scale appeared in some original centre of diffusion in West Asia and then spread to other centres of culture. This does not preclude the possibility of independent development in different centres.

Indus seals and inscriptions, as found in Mohenjo-daro, show that numbers were represented by vertical strokes arranged side by side or in lateral groups. This might probably be some kind of rod numerals, of which we have many examples in other ancient culture areas, notably among the Chinese and the Mayans.



How far they went with such rod numerals in representing higher numbers like 10, 20, 30 . . . or 100, 200 and so on, it is not possible to say. Some of the vertical or horizontal strokes, as we shall see later, survived in the Kharosṭhī and Brāhmī numerals.

MATHEMATICAL KNOWLEDGE AS REVEALED IN THE *SAṂHITĀS*, THE *BRĀHMAṆAS*, THE *VEDĀṄGAS* AND RELATED LITERATURE

SURVEY OF LITERATURE

In the chapter on survey of source materials, we have noticed briefly the various sections of the Vedic literature, e.g. the *Saṃhitās*, the *Brāhmaṇas* and the *Vedāṅgas*. This vast sacred literature contains enough material to help form a good idea of the mathematical ability of the Vedic Hindus. These materials are mostly scattered and diffused in the *Saṃhitās* and the *Brāhmaṇas*. We are somewhat more fortunate with regard to the *Vedāṅgas*, for two of them, the *Kalpasūtras* (ritual) and the *Jyotiṣa* (astronomy), directly concern a large body of mathematical knowledge without which neither the construction of various kinds of sacrificial altars nor the reckoning of time

[a] Mackay, pp. 348, 404.

for calendrical purposes would have been possible. This debt to mathematics or the science of calculation (*gaṇanā*, *rāśi-vidyā*) was freely acknowledged and the study of mathematics was always given a pride of place in the various branches of learning. When Sanat Kumāra wanted to know from Nārada the various sciences and arts the latter had studied, he gave a list which included astronomy and mathematics. In the *Vedāṅga Jyotiṣa*, the science of calculation has been likened to the crest on the peacock's head or the proverbial gem on the snake's hood. Mathematics, along with astronomy, was also held in high esteem by the Jaina and the Buddhist monks. One of the four branches of the religious literature of the Jainas, e.g. the *gaṇitānuyoga*, was concerned with the exposition of mathematical principles. The *Vinaya Piṭaka*, *Dīgha Nikāya*, *Divyāvadāna* and other Buddhist texts also expatiate on the importance of the study of *gaṇita* or *saṃkhyāna* (science of higher calculations).

We have referred to the *Kalpasūtras* as an important source of Vedic mathematics. One class of this ritual literature is the *Śrauta-sūtra* which deals with directions for the laying of sacrificial fires for *agnihotra*, the new and the full moon, the seasonal, the *soma* and other sacrifices. Of special importance for our purpose are sections called *Śulba-sūtras* which are directly attached to these *Śrauta-sūtras*. These sections deal with rules for the measurement and construction of the various sacrificial altars and consequently involve geometrical propositions and problems relating to rectilinear figures, their combinations and transformation, squaring the circle, circling the square as well as arithmetical and algebraic solutions of problems arising out of such measurements and constructions. The word *śulba* (also spelt as *śulva*) means a 'cord', a 'rope' or a 'string', and its root *śulb* signifies 'measuring' or 'act of measurement'.[a] Therefore, works entitled *śulba-sūtras* may be literally taken to mean a collection or compendium of rules concerning measurements with the help of a cord of various linear, spatial or three-dimensional figures. Quite appropriately, the *śulba-sūtras* represented the *Brāhmaṇa* geometry or mensuration, the *śulba-vijñāna*, as mentioned specifically in the *Mānava* and other *śulbas*, and the *śulbavid*, the expert geometer, was held in high esteem in the learned priestly circles.

One would expect a *śulba* section attached to each *Śrauta-sūtra*, and there are *Śrauta-sūtras* belonging to all the four *Saṃhitās*. But what we possess today are a small number of *śulba-sūtras* attached to the *Śrautas* belonging only to the various schools of the *Yajurveda*. Of them the Black Yajurvedins of the *Taittirīya* school were the most active, and produced the most comprehensive *śulbas*, e.g. those of Baudhāyana, Vādhula, Āpastamba and Hiraṇyakeśin. There are two *śulbas* by Mānava and Vārāha of the *Maitrāyaṇī* and one by Laugākṣi of the *Kāṭhaka-Kapiṣṭhala* school. Of the White Yajurvedins, Kātyāyana, the prolific *sūtrakāra*, is credited with a small but more scientifically executed *śulba* work. The

[a] Datta (4), p. 8.

initiative of the Yajurvedins in producing works of this kind is not surprising when we bear in mind that they were the principal custodians of the knowledge of sacrificial formulas and specialized in the techniques of performing various sacrifices.

The *Baudhāyana Śulba-sūtra* is the oldest (600–500 B.C.) and the most voluminous work of this class. It comprises 525 *sūtras* divided into three chapters. The first chapter of 116 *sūtras* gives geometrical propositions required for the construction of altars and deals with their relative positions and spatial magnitudes; the second chapter of 86 *sūtras* describes the various fire-altars (*agnis*) and their spatial relationships; the third chapter containing 323 *sūtras* is devoted to *kāmya agnis* or sacrificial altars designed to attain desired ends.

The *Mānava Śulba-sūtra* (posterior to Baudhāyana), a part of the *Śrauta-sūtra* by the same author, is a small compilation and gives specifications of the measuring tape, gnomon and methods of finding the cardinal points not given by Baudhāyana or Āpastamba. It contains descriptions of a number of altars, e.g. the *suparṇa-citi*, the *pākayājñikī*, the *marūti* and the *vāruṇi*, not found in other works.

The *Āpastamba Śulba-sūtra* (500–400 B.C.) comprises 223 *sūtras* distributed among six chapters. Āpastamba covers the same ground and gives the same rules as was done by Baudhāyana.

The *Kātyāyana Śulba-sūtra* (400–300 B.C.), also known as *Kātīya-śulbapariśiṣṭa*, is a comparatively small tract of 102 *sūtras* arranged in six chapters. Kātyāyana's treatment is more succinct and systematic. Like Mānava, he also gives specifications of the measuring tape, discusses the gnomon and its application in determining the cardinal points. Kātyāyana gives solutions of rational triangles and states the Pythagorean Theorem in a generalized form. In the *śulba*, Kātyāyana deals with different *agnis* and their spatial relations, but not with the *kāmya agnis*, because the latter is discussed in a separate chapter of his *Śrauta-sūtra.*

Other *śulba-sūtras* referred to are minor works and do not throw any additional light. Hiraṇyakeśin's work is no longer extant, but is known from references and occasional extracts in other *śulba-sūtras.*

We have already noticed the *Vedāṅga* and the *Ārca Jyotiṣa.* Although these are astronomical works, these offer examples of application of elementary mathematics in astronomical computations, divisions of the lunar zodiac, calculation of *tithis*, etc.

ARITHMETIC

Number

Like the Egyptians, the Vedic Hindus adopted 10 as the basis of numeration and developed a great interest in thinking out and naming large numbers. The Greeks, on the other hand, fought shy of large numbers and their terminology hardly took them beyond the 'myriad' (10^4). The Egyptians freely dealt with large numbers on the decimal scale, such as

hundred, thousand, million, tens of million and so on and had meaningful Hieroglyphic symbols to express them. The same is true of the Vedic Hindus. The various recensions of the *Yajurveda Saṃhitā* give names to numbers as large as 10^{12}. The *Taittirīya Saṃhitā*[a] gives the following denominations: *eka* (1), *daśa* (10), *śata* (10^2), *sahasra* (10^3), *ayuta* (10^4), *niyuta* (10^5), *prayuta* (10^6), *arbuda* (10^7), *nyarbuda* (10^8), *samudra* (10^9), *madhya* (10^{10}), *anta* (10^{11}) and *parārdha* (10^{12}). The same is repeated in the *Pañcaviṃśa Brāhmaṇa* with further extensions. The following passage from the *Pañcaviṃśa Brāhmaṇa*[b] will give an idea of the context and the manner in which large numbers were introduced:

> 'By sacrificing with the *agnihotra*, he reaches in one day ten "House-lords" (i.e. he becomes equal to, gains the merits of ten H.); by sacrificing with the *agnihotra* during ten years, he becomes equal to one who (regularly) performs the sacrifices of full and new moon, he becomes equal to one who performs the sacrifices of *soma*. By offering the *agniṣṭoma* sacrifices, he becomes equal to one who performs a sacrifice of a thousand cows as sacrificial fee. By offering ten of these, he becomes equal to one who performs a sacrifice with ten thousand *dakṣiṇās*. By offering ten of these, he becomes equal to one who sacrifices with a sacrifice of a hundred thousand *dakṣiṇās*. By offering ten of these, he becomes equal to one who sacrifices with a sacrifice of a million *dakṣiṇās*. By offering ten of these, he becomes equal to one who sacrifices with a sacrifice of 10 million *dakṣiṇās*. By offering ten of these, he becomes equal to one who sacrifices with a sacrifice of 100 million *dakṣiṇās*. By offering ten of these, he becomes equal to one who sacrifices with a sacrifice of 1,000 million *dakṣiṇās*. By offering ten of these, he becomes equal to one who sacrifices with a sacrifice of 10,000 million *dakṣiṇās*. By offering ten of these, he becomes equal to one who sacrifices with a sacrifice of 100,000 million *dakṣiṇās*. By offering ten of these he becomes the cow.'

The method of obtaining higher and higher numbers in multiples of 10, described later on as *daśaguṇottara*, is clearly indicated. The number names in this decimal scale in ascending order are: *eka*, *daśa*, *śata*, *sahasra*, etc., the same as given in the *Taittirīya Saṃhitā*. It appears that the thinking out and the naming of such large numbers were a favourite pastime of the ancient Indian mathematicians. The same tendency is noticed in the Buddhist literature where we find a centesimal scale (*śatottara gaṇanā*) and the name *tallakṣaṇa* for the number 10^{53}. The Jaina work, the *Anuyogadvāra-sūtra* (*c.* 100 B.C.), called the places in powers of 10 as *gaṇanā-sthāna* and mentioned large numbers up to 29 places and beyond. The Jainas are further credited with the conception of a time-scale called *śīrṣa-prahelikā* (8,400,000) and the suggestion of building up fantastically large numbers in ascending powers of this figure.

[a] *Taitt. S.*, 4.4.11.4.; 7.2.20.1.

[b] *Pañc. Br.*, xvii. 14.1.2; Eng. trans. by Caland.

The Vedic Hindus showed the same proficiency in developing a scientific vocabulary of number names, in which the principles of addition, subtraction and multiplication were conveniently used. The system required the naming of (1) the first nine digits, e.g. *eka, dvi, tri, catur, pañca, ṣaṭ, sapta, aṣṭa* and *nava*; (2) the second group of nine numbers obtained by multiplying each of the above digits by 10, e.g. *daśa, viṃśati, triṃśat, catvāriṃśat, pañcāśat, ṣaṣṭi, saptati, aśīti* and *navati*; and (3) the third group of 11 numbers beginning with 100 and followed by its multiples of 10 and its higher powers, e.g. *śata, sahasra, ayuta, ... parārdha* (*see* above). The multiplicative principle is already indicated in forming the numbers of the second and third group. Other examples are *ṣaṣṭiṃ sahasrāṇi, pañcāśat sahasram, dvā-saptatiḥ sahasrāṇi.* The additive principle is generally used in naming a number in which the numbers of the first and second group participate, e.g. *eka-daśa* (11), *sapta-viṃśati* (27), *aṣṭa-triṃśat* (38). Additive and multiplicative principles are simultaneously used when, in the number concerned, the members of the third group participate along with those of the second or the first, e.g. *sapta śatāni viṃśatiḥ* (720), *ṣaṣṭiṃ-sahasra navatiṃ nava* (60,099).[a] These principles were widely used in constructing number names in other culture areas, as witness such terms as *pente-deka* (50), *pente-hekaton* (500) among the Greeks.

Of greater importance, however, is the infrequent application of the subtractive principle for which the Etruscans are generally given the credit.[b] Proceeding from right to left, they wrote 27 as XIIIXX [20+(10−3)]; 38 as XIIXXX [30+(10−2)] and so on. The same subtractive principle, in the number nomenclature, was applied by the Vedic Hindus in the coinage of such terms as *ekānna-śata* (100−1), *ekānna-viṃśati* (20−1), *ekānna-catvāriṃśat*,[c] etc. The word *ekānna*, meaning 'one less', was later on shortened into *ekona* and *ūna*. In a limited way, the Babylonians also used this principle in forming their inauspicious number 19 as < < Y⅄ (20−1), where Y⅄ stands for −1.

Fundamental Operations

The four fundamental arithmetical operations, e.g. addition, subtraction, multiplication and division, are nowhere spelled out in the Vedic literature, as these were obviously taken for granted being commonplace operations. One, however, meets with the interesting case of dividing one thousand into three equal parts in the *Ṛgveda* and the *Brāhmaṇas.* In the *Ṛgveda,* the division of the thousand is not explicitly mentioned, but it is done so in the *Tattirīya Saṃhitā*[d] which, while incorporating the *ṛc,* modifies the last line as 'Ye did divide the thousand into three'. The full explanation of the arithmetical feat of Indra and Viṣṇu in the proposed

[a] *ṚV.* I. 164.11; I. 53.9.
[b] Smith (D. E.), II, p. 58.
[c] *Taitt. S.*, vii. 2.11.
[d] *Taitt. S.*, vi. 1.6.

division is given in the *Śatapatha Brāhmaṇa* as follows: 'For when Indra and Viṣṇu divided a thousand (cows) into three parts, there was one left, and here they caused to propagate herself in three kinds; and hence, even now, if anyone were to divide a thousand by three, one would remain over.'[a]

Fractions

Acquaintance with the fundamental arithmetical operations with elementary fractions is clearly indicated in the Vedic texts and their appendages. The *Ṛgveda* gives names of a number of simple fractions such as *ardha* ($\frac{1}{2}$), *tripāda* ($\frac{3}{4}$) and the *Maitrāyaṇī Saṃhitā* mentions *pāda* ($\frac{1}{4}$), *śapha* ($\frac{1}{8}$), *kuṣṭha* ($\frac{1}{12}$), *kalā* ($\frac{1}{16}$). From the *Śulba-sūtras* onwards we meet with terms such as *aṃśa, bhāga* to denote fractions in general. These terms are used in combination with cardinal or ordinal number names; in the case of the latter the word *aṃśa* or *bhāga* is often omitted. A few examples follow:

tribhāga, tryaṃśa	$= \frac{1}{3}$
pañcama-bhāga, pañcama	$= \frac{1}{5}$
dvādaśa-bhāga or *dvādaśa*	$= \frac{1}{12}$
pañcadaśa-bhāga	$= \frac{1}{15}$
tri-aṣṭama, tryaṣṭa	$= \frac{3}{8}$
dvi-saptama	$= \frac{2}{7}$
trayastryaṣṭa	$= 3\frac{3}{8}$
pañcamasya caturviṃśa	$= \frac{1}{24}$ of $\frac{1}{5}$

There are a number of other peculiar modes of expressing fractions, e.g. *ardhāṣṭama* ($7\frac{1}{2}$), *ardhanavama* ($8\frac{1}{2}$), *ardhadaśama* ($9\frac{1}{2}$)[b] or *dvi-guṇa* ($\frac{1}{2}$), *tri-guṇa* ($\frac{1}{3}$), *caturguṇa* ($\frac{1}{4}$).[c]

The *Śulba-sūtras* contain several instances of addition, subtraction, multiplication, division and the squaring of fractions. Consider the following example from Baudhāyana:[d]

> 'Then he measures the area of this square-shaped *citi*, whose side is three *puruṣas* less one-third. At the western side of this square is the handle whose east-west length is half a *puruṣa* plus ten *aṅgulas* (one-twelfth *puruṣa*) and north-south breadth one *puruṣa* less one-third. This makes the (area of the) *agni* sevenfold plus two *aratnis* and the *prādeśa*.'

Two *aratnis* and the *prādeśa* equal 60 *aṅgulas* or $\frac{1}{2}$ *puruṣa*. Expressed in figures, the above means:

$$\text{The area of the } agni = \left(3-\tfrac{1}{3}\right)^2+\left(\tfrac{1}{2}+\tfrac{1}{12}\right)\left(1-\tfrac{1}{3}\right) = 7\tfrac{1}{2}.$$

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[a] *Śat. Br.*, iii. 3.1.13.
[b] *Bśl.*, ii. 1–3.
[c] *Mśl.*, v. 5.
[d] *Bśl.*, iii. 219–24.

The results of a few more statements of this nature are given below:

(1) Number of bricks each $\frac{1}{25}$ sq. *puruṣa* to cover $7\frac{1}{2}$ sq. *puruṣa*

$$= 7\frac{1}{2} \div \frac{1}{25} = 187\frac{1}{2}$$

(2) Number of bricks each $\frac{1}{15}$ of $\frac{1}{2}$ sq. *puruṣa* to cover $7\frac{1}{2}$ sq. *puruṣa*

$$= 7\frac{1}{2} \div \frac{1}{15} \text{ of } \frac{1}{2} = \frac{15}{2} \div \frac{1}{30} = \frac{15}{2} \times 30 = 225.$$

Progressive Series

Indian interest in progressive series has been traced to the *Saṃhitās*. The *Taittirīya Saṃhitā* indicates the following arithmetical series in which the odd (*ayugma*) and the even (*yugma*) ones are noticeable:

1,	3,	5, ...	19,	29,	39, ...	99
2,	4,	6,	20			
4,	8,	12,	20			
5,	10,	15,	100			
10,	20,	30,	100			

The *Pañcaviṃśa Brāhmaṇa*[a] prescribes *dakṣiṇās* in gold measures (*mānas*) to be given in geometrical progressions, depending on the nature and the time of offerings, as follows:

12 (gold *mānas*), 24, 48, 96, 192 ... 3072, 6144 ... 49152, 98304, 196608, 393216.

In the above examples, the summations of such series are not given. This is correctly done in the *Śatapatha Brāhmaṇa*[b] as follows: '... there are seven of these meters, increasing by four syllables; and the triplets of these make seven hundred and twenty syllables and thirty-six in addition thereto.'

In other words, it is proposed to compute

$$3(24+28+32+\ldots 7 \text{ terms}) = 3\times \frac{7}{2}\{2\times 24+(7-1)\times 4\} = 756.$$

It is true that no general rule for finding the summation as indicated above is given in the *Śatapatha Brāhmaṇa*. But the recurrence of both arithmetical and geometrical series, with the correct statement of the results of their summation, strongly suggests that the Vedic Hindus probably possessed some method of finding the summation of such series. Thus the *Bṛhaddevatā* (400 B.C.) gives the summation

$$2+3+4+\ldots+1000 = 500499$$

and Bhadrabāhu's *Kalpasūtra* (300 B.C.), a Jaina canonical work, the summation of the geometrical series

$$1+2+4+\ldots+8192 = 16383.$$

The series played an important part in prosody. Piṅgala, in his *Chandaḥsūtra* (200 B.C.), used a geometrical series 2, 2^2, 2^3 ...

[a] *Pañc. Br.*, xviii. 3. [b] *Śat. Br.*, x. 5.4.7

It is noteworthy that the summation of progressive series has ever since continued to occupy the attention of subsequent Indian mathematicians such as Mahāvīra, Bhāskara II, Nārāyaṇa and others who have all given general formulas for obtaining the sum. In the *Sthānāṅgasūtra*, progressive series is included in the mathematical topic *Vyavahāra*, as explained by the commentator Abhayadeva Sūrī (A.D. 1050). Later on, it became the subject of special treatises, e.g. *Bṛhaddhāra Parikarma*, referred to by Nemicandra.

GEOMETRY

Postulates

We have already stated that the various *śulba-sūtras* that have come down to us as parts of the *Śrauta-sūtras* are Brāhmaṇic geometrical manuals for the construction of sacrificial altars. In the various rules given, certain assumptions resembling Euclidean postulates are taken for granted. Thus a straight line is capable of division into an infinite number of equal parts; a circle can be divided into any number of parts by drawing diameters; each diagonal bisects a rectangle and both diagonals bisect each other, dividing the rectangle into four parts with the vertically opposite ones equal in all respects; a straight line joining the vertex with the middle point of the opposite side divides an isosceles triangle into two equal halves; parallelograms drawn on the same base and between the same parallels are equal to one another; a square inscribed within a circle and touching the circumference is the maximum, and so on. The texts give several rules as to how to construct a straight line perpendicular to another straight line, a square with a given side, a rectangle with given sides, an isosceles trapezium of a

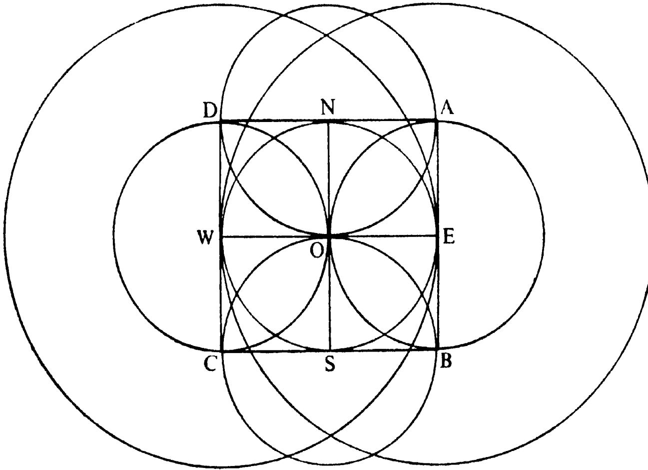


FIG. 3.2.

given altitude, face and base. For constructing a square, Baudhāyana gives, among others, the following rule:

'If you intend to draw a square, take a cord of length equal to the side desired of the square. Make a tie at each end of the cord and mark its middle point. Draw the east-west line (*EW* of Fig. 3.2) and fix a pole at its middle (*O*). After fastening the two ties at that pole draw a circle with the mid-point of the cord; fix a pole at each end of the diameter (along the east-west line). Fasten one tie at the eastern pole and draw a circle with the other tie. Likewise, draw a circle round the western pole. Join the points of intersections of these circles to obtain the second (north-south) diameter; fix a pole at each end of this diameter. Fasten both ties at the east pole and describe a circle with the mid-point (of the cord). Draw similar circles around the southern, the western and the northern poles. The exterior points of intersection of these four circles will give the four corners (*ABCD*) of the required square.'[a]

Combinations and Transformations of Rectilinear Figures

Of greater importance are the rules given in the *śulbas* for the combination and transformation of rectilinear figures, specially the squares and the rectangles. In a series of rules for transforming a square into a rectangle, the simplest one is to draw the diagonal *AC* of the square *ABCD* to divide it into two equal parts, to divide again one of these parts into two equal parts by joining the vertex *D* with the mid-point *E* of the diagonal and then to fit them suitably one to each side *AB* and *BC* of the square. *AFGC* is then the required rectangle. In the *paitṛkīvedi*, it is often required to find one square double of another given square. This is done by joining the mid-points of the sides of a square. The thing is achieved by drawing on the other side of the diagonal in Fig. 3.3 a similar rectangle *AHIC*.

When one side of a rectangle is given, the rule of transforming a square into a rectangle of the given side is given by Āpastamba as follows:[b]

> 'If you desire to make a rectangle out of a square (cut off from it a rectangle) of a side of the desired length. The excess remaining is to be added suitably as to fit (the rectangle cut off).'

Baudhāyana also gives a similar rule.[c] The directions are incomplete but, according to interpretations given of the above rule by the commentators Sundararāja and Dvārakānātha Yajvā, the true process appears to be as illustrated in Fig. 3.4. *ABCD* is the given square. Its side *AB* is extended to *E*, so that *EB* equals the given side of the rectangle into which the square is to be transformed. Join *EC* cutting *AD* at *O*. Complete the rectangles *EFCB* and *GFCH*. Then *GFCH* is the required rectangle. From the postulate that a rectangle is bisected by its diagonal, it is easy to see that the rectangles *AOHB*, *GODF* are equal in areas and therefore the square *ABCD* equals the rectangle *GFCH*.

---

[a] *Bśl.*, i. 22–28. [b] *Āśl.*, iii. 1. [c] *Bśl.*, i. 53.

Baudhāyana, Āpastamba and Kātyāyana all teach methods of constructing a square equal to the sum of two different squares. The method

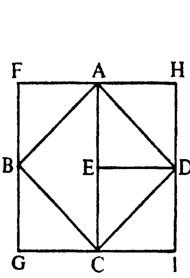


Fig. 3.3.

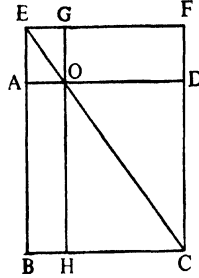


Fig. 3.4.

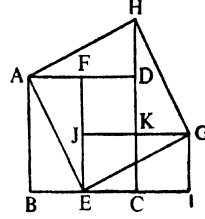


Fig. 3.5.

is to cut off from the larger of the two given squares, *ABCD*, a rectangular portion *ABEF* of which the side *BE* is equal to the side of the given smaller square. Then the diagonal *AE* is the side of the square equal to the sum of the two given squares. The proof will follow from Fig. 3.5, in which *AEGH* is the required square, and *ABCD* and *CKGI* are the given squares.[a] In other words, the proposed construction is based on what has generally come to be known as the theorem of Pythagoras.

Pythagorean Theorem

The theorem of the square of the diagonal is more explicitly given in more or less the same language in all the *śulba-sūtras* we know of. Here is Baudhāyana's definition:[b]

> *dīrghacaturasrasyākṣṇayārajjuḥ pārśvamānī tiryaṅmānī ca*
> *yatpṛthagbhūte kurutastadubhayaṃ karoti* |
>
> 'The diagonal of a rectangle produces by itself both (the areas) produced separately by its two sides.'

The same definition is given by Āpastamba. Kātyāyana's definition given in the same language is characterized by the explicit mention of the knowledge of plane figures:

> *dīrghacaturasrasyākṣṇayārajjustiryaṅmānī pārśvamānī ca yat*
> *pṛthagbhūte kurutastadubhayaṃ karotīti kṣetrajñānam* |

Note the word *iti kṣetrajñānam* at the end, meaning 'this is the knowledge of plane figures'.

A question has often been asked whether such a definition resulted from empirical guesswork or was based on a proof of some kind. Although it is too much to expect elaboration of a proof in manuals of this type there is hardly any doubt that the Vedic *śulbavids* at this distant date possessed a valid proof of the theorem, of which the texts themselves provide

[a] Datta (4), p. 77.

[b] *BŚl.*, i. 48.

reliable indications. For example, Baudhāyana, in the very next rule,[a] says that the rectangles for which the above is true have their sides 3 and 4, 12 and 5, 15 and 8, 7 and 24, 12 and 35, 15 and 36. The sum of squares of these numbers is also a square for each pair.

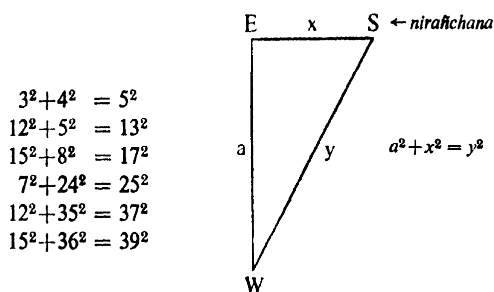


FIG. 3.6.

The above relationships between sides and diagonals or hypotenuse for rational rectangles or triangles have been freely used for finding the perpendicular directions (north-south) at the east or the west point of the east-west line in altar settings. The method is to take a cord of suitable length greater than the distance between the two poles one each at the east and the west point, fasten a loop at either end of the cord, fix it with the two poles by these loops and then stretch it by the *nirañchana* mark. The *nirañchana* mark divides the cord in two portions x and y such that $a^2+x^2 = y^2$, where a is the distance between the east-west pole (Fig. 3.6). This finding of the properties of rational triangles is a strong argument in favour of the Vedic Hindus possessing proofs of the theorem of the square of diagonal or the hypotenuse. It is possible that by actually drawing the squares on the diagonal and the sides of a rational rectangle, dividing them into elementary unit squares and then counting them, they might have arrived at the truth of this theorem (Fig. 3.7).

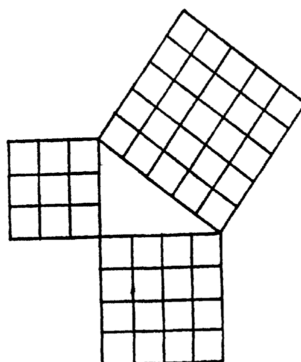


FIG. 3.7.

Question of Origin

The question of the Greek origin of the theorem and also whether Pythagoras himself was the discoverer of it and its proof has by no means been solved. The tradition attributing the theorem to pythagoras is due to Cicero (*c.* 50 B.C.), Diogenes Laertius (second century A.D.), Athenaeus (*c.* A.D. 300), Heron (third

[a] *BŚl.*, i. 49.

century A.D.), and Proclus (*c.* A.D. 460), and therefore started about five centuries after the death of Pythagoras. Junge pointed out that the Greek literature of the first five centuries after Pythagoras contained no mention of the discovery of this or any other important geometrical theorem by the great philosopher and furthermore emphasized uncertainties in the statements of Plutarch and Proclus. Although various attempts have been made to justify the tradition and trace the proof to Pythagoras, no record of proof has come down to us earlier than that given by Euclid (Theorem 47, BK I). As to the relation $4^2+3^2 = 5^2$ from which the theorem of rational triangle is derivable, very ancient Egyptian knowledge is attested by the Kahun papyrus of the twelfth dynasty (*c.* 2000 B.C.), but its association with rational triangles does not seem indicated in this or other Egyptian papyrii.[a] It is interesting to note that among the Egyptians, geometry of surveying was considered to be the science of the 'rope-stretchers' (*harpedonap'tae*) who thus appear to be the Egyptian counterpart of the Indian *śulbavids*. As to the antiquity of Pythagorean theorem in China, it is stated, though not proved, in the arithmetical classic *Chou Pei Suan Ching* (third or fourth century B.C.); the numerical relationship 4, 3 and 5 between the sides and the diagonal of a rational rectangle is also given in this text.

Areas and Volumes

Regarding other areas of geometry, the areas and volumes of a number of plane and solid figures have been given as follows:

Area of a triangle = $\frac{1}{2}$(base) × (altitude)
Area of a parallelogram = (base) × (altitude)
Area of a trapezium = $\frac{1}{2}$(sum of two parallel sides) × (altitude)
Volume of a prism or cylinder = (base) × (height)

$$\text{Volume of the frustum of a pyramid} = \frac{(a+a')}{2}\,\frac{(b+b')}{2}\,h,$$

where a, b are the length and breadth of the rectangular base, a', b' the corresponding ones of the parallel face, and h is the height.

Squaring the Circle; π

Another type of problem which interested the *śulba* geometers was the circling of the square or its converse the squaring of the circle. Through these exercises, the Vedic Hindus were led to finding approximate values of π. For circling a square, Baudhāyana's rule is first to draw the arc of a circle about the centre O of the given square $ABCD$ with a radius equal to half the diagonal, intercepting the east-west line at P. Then the circle drawn about the centre O with a radius equal to half the side of the square plus one-third of the portion between the (previous) circle and the square ($OQ = OR+QR$ where $QR = PR/3$) answers for the problem. If the side

[a] Heath, I, p. 352.

of the given square be $2a$, the radius of the required circle works out to $a \times 1{\cdot}1380718$, taking the value of $\sqrt{2} = 1{\cdot}4142156$ as given in the *śulba* (*vide infra*). That the area of the circle $4{\cdot}068987a^2$ is somewhat higher than $4a^2$ is fully reflected in the *śulba-sūtras*.

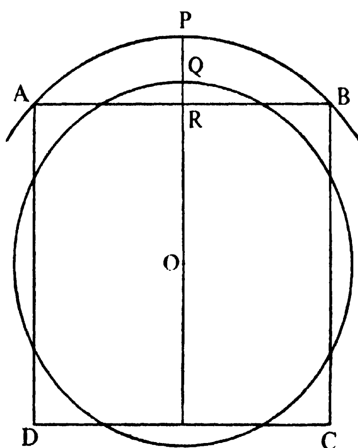


FIG. 3.8.

For squaring a circle, the same *śulba-sūtra* advises the diameter to be first divided into eight equal parts. The last 1/8th part is further divided into 29 parts and then 28 of these subdivisions are rejected (from this 1/8th part). Furthermore, from it is rejected 1/6th of the preceding subdivision $\left(\frac{1}{8.29}\right)$ minus 1/8th part of the last subdivision. If d be the diameter of the circle, the side of the required square is given by

$$\frac{7d}{8}+\frac{d}{8}-\frac{28d}{8.29}-\left(\frac{d}{8.29.6}-\frac{d}{8.29.6.8}\right)=\frac{1224}{1393}d \text{ (approx.).}$$

From the foregoing operations, it is possible to calculate the value of π. In the example of circling of the square, the radius r in terms of a, half the side of the square is given by

$$r = a+\frac{a}{3}(\sqrt{2}-1),$$

where

$$\pi = \frac{4a^2}{\left[a+\frac{a}{3}(\sqrt{2}-1)\right]^2} = \frac{4}{[1+\frac{1}{3}(\sqrt{2}-1)]^2} = 3{\cdot}0883$$

accepting the *śulba* value of $\sqrt{2}$. Other results are 3·0885, 3·004. Baudhāyana's use of 3 as the value of π is therefore quite understandable. A more accurate value of π, e.g. 3·16049, is inferable from the data given in the *Mānava Śulba-sūtra*.

ALGEBRA

The altar geometry of the *Śulba-sūtras* does not fail to give us a glimpse of the beginnings of algebraic notions among the Vedic Hindus. These notions include quadratic equations, indeterminate equations, surds, conception of irrational numbers and determinations of their approximate values.

Quadratic Equation

The sacrificial ritual often necessitated enlargement or reduction of the altar in accordance with a number of plans. According to one plan, the shape is to remain the same, all sides being proportionally increased or decreased. The standard *mahāvedi*, for example, has the shape of an isosceles trapezium having for its face, base and altitude 24, 30 and 36 units respectively (area 972 sq. units). The standard *śyena-cit* (the falcon-shaped altar) consists of a central trunk of 4 sq. units, two rectangular wings each measuring 1 by $1\frac{1}{5}$ or $1\frac{1}{5}$ sq. units and a rectangular tail (*prādeśa*) 1 by $1\frac{1}{10}$ or $1\frac{1}{10}$ sq. units and has a total area of $7\frac{1}{2}$ sq. units.

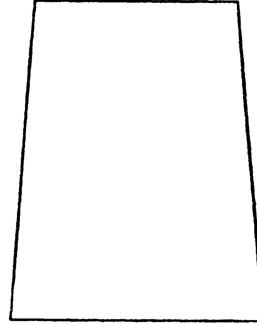


FIG. 3.9*a*. *Mahāvedi*.

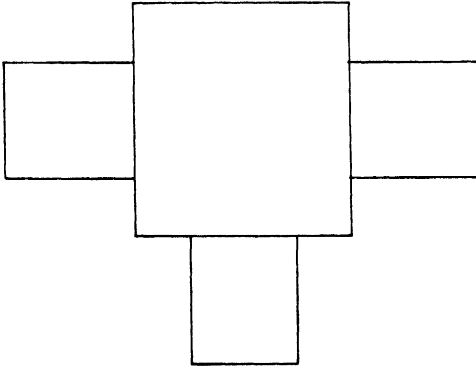


FIG. 3.9*b*. *Śyena-cit*.

By the first plan, the measures are left undisturbed but the unit of length is changed as required. According to another plan, some parts of the altar are proportionately increased while others are left undisturbed. Thus, in the case of *śyena-cit*, while the units for the complete square are proportionately changed, that of the fractional parts for the two *aratnis* and one *prādeśa* are left unchanged. If p represents the modified unit and α the change in area, we obtain the following quadratic equations for the two types of *vedis* mentioned above:

Plan I: *Mahāvedi*: $$36p \times \frac{(30p+24p)}{2} = \frac{36 \times (30+24)}{2} + \alpha$$

$$972p^2 = \alpha + 972$$

$$\text{Śyena-cit:}\quad 2p\times 2p+2\left[p\left(p+\frac{p}{5}\right)\right]+p\left(p+\frac{p}{10}\right)=\frac{15}{2}+\alpha$$

$$15p^2 = 2\alpha+15$$

$$\text{Plan II: Śyena-cit:}\quad 2p\times 2p+2\left[p\left(p+\frac{1}{5}\right)\right]+p\left[p+\frac{1}{10}\right]=\frac{15}{2}+\alpha$$

$$14p^2+p = 2\alpha+15$$

Specific examples given in the *śulba-sūtras* of Baudhāyana, Āpastamba and Kātyāyana agree with the solutions of these equations.

Indeterminate Equations

The *śulbas* contain rules for the construction of a square n times a given square. The rule involves the application of the diagonal square theorem, for it says that the diagonal of the square produces the double square, the diagonal of the rectangle formed of the previous diagonal and the side of the given square gives a square thrice as large, the diagonal of the rectangle formed of the previous diagonal and the side of the given square produces a fourfold square and so on. Kātyāyana gives a general rule for finding a square n times a given square. According to this rule, the required square will be given by the altitude of an isosceles triangle whose base is $(n-1)$ times and the sum of the two equal sides $(n+1)$ times the side of the given square. That is, in Fig. 3.10,

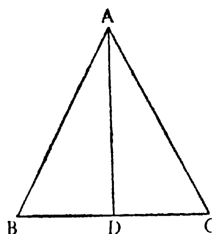


FIG. 3.10.

$$BC = (n-1)a,\quad AB = AC = \frac{(n+1)}{2}a,$$

where a is the side of the given square. It is clear that

$$AD^2 = \left[\frac{(n+1)a}{2}\right]^2 - \left[\frac{(n-1)a}{2}\right]^2 = na^2.$$

If we put $n = m^2$, the above leads to

$$m^2a^2+\left(\frac{m^2-1}{2}\right)^2a^2 = \left(\frac{m^2+1}{2}\right)^2a^2$$

which is a solution of indeterminate equation of the second degree

$$x^2+y^2 = z^2.$$

The questions relating to finding the sizes and number of bricks required for building the different layers of the altars envisage solutions of simultaneous indeterminate equations of the first degree. The *Baudhāyana Śulba-sūtra* prescribes that a *gārhapatya vedi* should be constructed with five

layers of bricks, each layer containing 21 bricks so arranged that their rift in two consecutive layers do not coincide. For a square altar in which square bricks are used, Baudhāyana says that three kinds of bricks having their sides 1/6, 1/4 and 1/3 of the side (*vyāyāma*) of the altar should answer for the construction. How were the sizes as well as the number of bricks determined? Since 21 is not a square number and the rifts of consecutive layers must not coincide, square bricks of at least three different sides must be used. Suppose a to be the side of the square altar and l_1, l_2, l_3 the side of each of the three square bricks so that $l_1p_1 = l_2p_2 = l_3p_3 = a$, where p_1, p_2, p_3 are rational integers. If x and y be the number of bricks of sides l_1 and l_2 for the first layer, and x' and y' those of sides l_3 and l_1 for the second layer, we have

for the first layer,

$$x+y = 21$$

$$xl_1^2+yl_2^2 = a^2$$

$$\frac{x}{p_1^2}+\frac{y}{p_2^2} = 1$$

for the second layer,

$$x'+y' = 21$$

$$\frac{x'}{p_3^2}+\frac{y'}{p_1^2} = 1.$$

In other words, the problem leads to the following simultaneous indeterminate equations of the first degree:

$$x+y = 21$$

$$\frac{x}{m^2}+\frac{y}{n^2} = 1$$

where m and n are integral parts of a. Although the method of solution is not indicated, Baudhāyana gives correctly the values of m and n as 6 and 4 for $x = 9$, $y = 12$ and again as 3 and 6 for $x = 5$ and $y = 16$.

Surds

The technical expressions used in the *śulbas* for such quantities as $\sqrt{2}$, $\sqrt{3}$, $\sqrt{4}$, $\sqrt{18}$, etc., are *dvi-karaṇī, tṛ-karaṇī, catuṣkaraṇī, aṣṭādaśa-karaṇī,* etc. By using words for ordinal numbers along with *karaṇī*, quantities $\sqrt{\frac{1}{3}}$, $\sqrt{\frac{1}{7}}$ are expressed as *tṛtīya-karaṇī, saptama-karaṇī,* etc. Thus *karaṇī* has been used in the same sense as root or surd. Elementary operations with surds are clearly indicated in the various places of the texts. To draw a *sautramaṇikī vedi*, an isosceles trapezium of the same shape as, but one-third the area of, the *mahāvedi*, Āpastamba uses the surds as follows: 'For a unit *prakrama* $1/\sqrt{3}$ of a *prakrama* is to be substituted;

alternatively, the transverse sides should be 8 and 10 times $\sqrt{3}$ and the east-west line 12 times $\sqrt{3}$.'[a] Expressed in figures,

$$\text{the first direction gives the area} = \frac{36}{\sqrt{3}}\cdot\frac{1}{2}\left(\frac{24}{\sqrt{3}}+\frac{30}{\sqrt{3}}\right)$$
$$= 324 \text{ sq. units;}$$
$$\text{the second direction gives the area} = 12\sqrt{3}\times\tfrac{1}{2}(8\sqrt{3}+10\sqrt{3})$$
$$= 324 \text{ sq. units.}$$

Irrational Numbers and their Approximate Values

The Vedic Hindus have been credited further with the notion of irrationality of the quantities $\sqrt{2}$, $\sqrt{3}$. They have even given the values of such irrational numbers up to a high degree of approximation. For the value of $\sqrt{2}$, the exact wordings of some of the *śulbakāras* are quoted below:

> *pramāṇaṃ tṛtīyena vardhayettacca caturthenātmacatus-trimśonena | saviśeṣaḥ |*[b]
>
> *karaṇīṃ tṛtīyena vardhayettacca svacathurthenātma-catustrimśonena saviśeṣa iti viśeṣaḥ*[c]

Both versions having used practically the same wordings, these may be rendered as follows:

> 'Increase the measure by its third and this third by its own fourth less the thirty-fourth part of that fourth. This is the value with a special quantity in excess.'[d]

If we take 1 for the measure of a square side, the above formula gives the diagonal as follows:

$$\sqrt{2} = 1+\frac{1}{3}+\frac{1}{3.4}-\frac{1}{3.4.34} = 1{\cdot}4142156.$$

In the same manner, the value of *tṛ-karaṇī* is given by

$$\sqrt{3} = 1+\frac{2}{3}+\frac{1}{3.5}-\frac{1}{3.5.52} = 1{\cdot}7320513.$$

The method by which the values of these irrationals were obtained is not indicated in the texts. They did not obviously know how to extract the square root up to so many decimal places at this distant time. Thibaut, Bürk, Müller, Datta and others have reconstructed possible methods out of the very elements and procedures dealt with in the *śulbas*. For $\sqrt{2}$, one possible method appears to be as follows:

Two squares of unit side are taken. One of them is divided into three equal rectangular strips, of which the first and the second are marked 1

[a] *ĀŚl.*, v. 8.
[b] *BŚl.*, i. 61–62; *ĀŚl.*, i. 6.
[c] *KŚl.*, ii. 13.
[d] Thibaut (1), p. 21; Datta (4), pp. 188 ff.

and 2. The third strip is subdivided into three squares of which the first is marked 3. The remaining two squares are each divided into four equal strips marked by 4, 5, 6, 7 and 8, 9, 10, 11. These eleven strips are added to the other square in the manner shown in Fig. 3.11 to obtain a square less a small square (shaded) at the corner. The side of the square equals $1+\frac{1}{3}+\frac{1}{3.4}$ and the area of the shaded square $\left(\frac{1}{3.4}\right)^2$, so that the former is greater than the sum of the two original squares by the amount $\left(\frac{1}{3.4}\right)^2$.

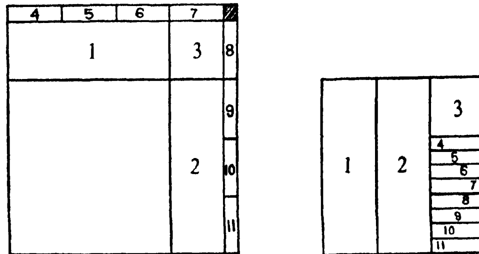


Fig. 3.11.

To find the approximate value, suppose x be the thickness of the smallest strips, 4, 5, . . . 11. Then

$$2x\left(1+\frac{1}{3}+\frac{1}{3.4}\right)-x^2 = \left(\frac{1}{3.4}\right)^2$$

or

$$x = \frac{1}{3.4.34}, \text{ neglecting } x^2 \text{ which is too small.}$$

The side of the square equalling the sum of the two original squares or the diagonal of each of the original square is given by

$$\sqrt{2} = 1+\frac{1}{3}+\frac{1}{3.4}-\frac{1}{3.4.34}.$$

One of the cuneiform tablets from the old Babylonian times (1600 B.C.), now in the Yale Babylonian collection, shows a square with its two diagonals and values in sexagesimal system, from which $\sqrt{2}$ in the same system works out as

$$\sqrt{2} = 1;\ 24, 51, 10.$$

Neugebauer[a] has shown that the sexagesimal equivalent of the value of $\sqrt{2}$ as given in the *Śulba-sūtras* is 1; 24, 51, 10, 37, . . . He has further hazarded a guess that both the main term and the subtractive correction of the Hindu value were based ultimately on Balylonian approximations. The more ancient character of the Babylonian cuneiform texts cannot, however, be doubted. Serious objections have been raised in accepting any date for the earliest of the *Śulba-sūtras* beyond 500 B.C. But that itself does not appear to be a reliable ground for making such a suggestion in view of a more complete and clear textual statement and several

[a] Neugebauer (1), p. 34.

indications of the derivations of approximate values, embedded in the very texts themselves.

Permutations, Combinations and Pascal Triangle

Another favourite mathematical pursuit of the Vedic Hindus was in the field of permutations and combinations, which was also very popular among the ancient Jainas about whose mathematical interests we shall speak presently. This interest was undoubtedly activated by the considerations of the Vedic meters and their variations. There are several Vedic meters, e.g. *Gāyatri*, *Anuṣṭubh*, *Bṛhatī*, *Triṣṭubh*, *Jagatī*, to mention a few, with 6, 8, 9, 11, 12 syllables. The Vedic meter specialists were concerned with the problem of producing different possible types of meters from those of varying syllables by changing the long and short sounds within each syllable group. In this effort, they were led invariably to laying the foundation of the mathematics of permutations and combinations. Emerging from the intricacies of the Vedic meters, these rules found immediate applications, e.g. finding possible combinations of the six tastes taking one, two, three, etc., at a time,[a] possible numbers of philosophical categories through combinations of n fundamental categories taken one, two, three, etc., at a time,[b] total number of perfumes that can be made from sixteen different substances taken one, two, three or four substances at a time,[c] and so on. In all these examples, the results are given correctly.

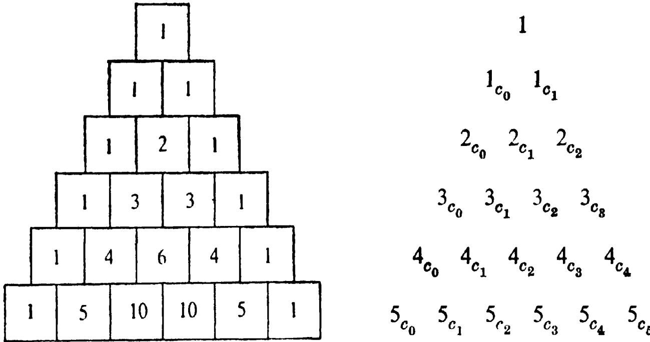
Special importance attaches to Piṅgala's *Chandaḥ-sūtra* (200 B.C.) which contains a method called *meru-prastāra* for finding the number of combinations of n syllables taken 1, 2, 3 . . . n at a time. The method, as explained by the commentator Halāyudha (tenth century A.D.), is as follows:

> 'After drawing a square on the top, two squares are drawn below (side by side) so that half of each is extended on either side. Below it three squares, below it (again) four squares are drawn and the process is repeated till the desired pyramid is attained. In the (topmost) first square the symbol for one is to be marked. Then in each of the two squares of the second line figure one is to be placed. Then in the third line figure one is to be placed on each of the two extreme squares. In the middle square (of the third line) the sum of the figures in the two squares immediately above is to be placed; this is the meaning of the term *pūrṇa*. In the fourth line one is to be placed in each of the two extreme squares. In each of the two middle squares, the sum of the figures in the two squares immediately above, that is three, is placed. Subsequent squares are filled in this way. Thus the second line gives the expansion of combinations of (short and long sounds forming) one syllable; the third line the same for two syllables, the fourth line for three syllables, and so on.'[d]

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[a] *SS. Rasabheda-vikalpādhyāya*, 63.
[b] *Bhag. Sū.*, 314.
[c] *Bṛh. S.*, lxxvii. 13–14.
[d] Bag, pp. 72–73.

The *meru-prastāra* is the same as the triangular array known in Europe as Pascal's triangle. The triangle first appeared in Europe on the title page of the arithmetic of Apianus (A.D. 1527) and subsequently in the works of Stifel (A.D. 1544), Scheubel (A.D. 1545), Tartaglia (A.D. 1556),



$$
\begin{array}{c}
1 \\
{}^{1}c_0 \quad {}^{1}c_1 \\
{}^{2}c_0 \quad {}^{2}c_1 \quad {}^{2}c_2 \\
{}^{3}c_0 \quad {}^{3}c_1 \quad {}^{3}c_2 \quad {}^{3}c_3 \\
{}^{4}c_0 \quad {}^{4}c_1 \quad {}^{4}c_2 \quad {}^{4}c_3 \quad {}^{4}c_4 \\
{}^{5}c_0 \quad {}^{5}c_1 \quad {}^{5}c_2 \quad {}^{5}c_3 \quad {}^{5}c_4 \quad {}^{5}c_5
\end{array}
$$

FIG. 3.12.

Bombelli (A.D. 1572) and other Renaissance methematicians and in Pascal's posthumous work *Traité du triangle arithmétique* (1665). Apart from giving a quick method of finding the number of combinations, the method in its association with meters clearly envisaged the computation of the binomial terms a^n, $a^{n-1}b$, . . . ab^{n-1}, b^n of the expression $(a+b)^n$.

JAINA MATHEMATICS

Despite great interest attached to mathematics by the Jainas of ancient India, very little of their mathematical effort has unfortunately survived to this day. We have of course the mid-ninth century mathematical classic *Gaṇita-sāra-saṃgraha* by Mahāvīra (*c*. A.D. 850), but no such comparable work belonging to the pre-Christian centuries is extant. We only have a few fragments or insertions in canonical or other types of non-mathematical literature from which to judge of their early achievements. That a good body of mathematical literature must have existed at one time seems indicated in Mahāvīra's own statement in which he described himself as a mere compiler from the great ocean of the knowledge of mathematics from which long lines of holy sages had skilfully gathered many precious mathematical gems. About the first century B.C. the *Sthānāṅga-sūtra*, a Jaina canonical work, listed several mathematical topics which used to be cultivated at that time. These topics are: *saṃkhyāyana* (science of numbers), *parikarma* (fundamental operations), *vyavahāra* (subjects of treatment), *rajju* (geometry, like *śulba*), *rāśi* (heap, solid mensuration), *kalāsavarṇa* (fractions), *yāvat-tāvat* (equations, algebra), *varga* (square, quadratic equations), *ghana* (cube, cubic equations), *varga-varga* (biquadratic equations) and *vikalpa*

(permutations and combinations). The Sanskrit version of the above enumeration in Pali runs as follows:

parikarma rajjuḥ rāśiḥ vyavahārastathā kalāsavarṇaśca |
pudgalāḥ yāvattāvat bhavanti ghana ghanamūlaṃ vargaḥ vargamūlam ||

These subjects and the various technical terms used by the Jainas passed later on into the mathematical works of scholars irrespective of their religious beliefs and adherences. It is thus quite reasonable to believe that in the period intervening the literature of the *Brāhmaṇas* and the *Sūtras* of the various Vedic schools and the period of specialization and Siddhāntic astronomy from about the fourth or fifth century A.D. the Jaina mathematicians played a significant role. The disappearance of their works might be due to (*a*) supersession of their simple processes and methods by better and more sophisticated ones due to Āryabhaṭa, Brahmagupta, Mahāvīra, Śrīpati, Śrīdhara, Bhāskara and others and (*b*) progressive deterioration of the culture of mathematics in their religious order.

Jaina Mathematical Sources

As to early Jaina mathematical sources, we have already referred to the *Sūryaprajñapti* and the *Candraprajñapti* which, although astronomical works, contain useful information about mathematics as well. Like the *Sthānāṅga-sūtra*, we have stray references of mathematical and astronomical importance in canonical works like the *Bhagavatī-sūtra* (first century B.C.), the *Uttarādhyāyana-sūtra* (first century A.D.) and the *Anuyogadvāra-sūtra* (first century A.D.). As to persons by name, mention should be made of Bhadrabāhu (d. 298 B.C.), who had the unusual gift of reproducing from memory the entire canonical literature of the Jainas and was befittingly called a *śrutakevalin*. He wrote a commentary on the *Sūryaprajñapti*, as we know from Malayagiri and possibly a compendious *Saṃhitā* known after his name. Bühler noticed a work entitled *Bhadrabāhavī Saṃhitā*, but it has not been established that it was the work of Bhadrabāhu we are considering. Umāsvāti (*c.* first century A.D.), the reputed Jaina metaphysician and author of *Tattvārthādhigama-sūtra-bhāṣya* was, of course, no mathematician but referred to mathematical formulae in his metaphors, which indicate that such mathematical topics must have been widely current at least among the intelligentsia of his time. Both Bhadrabāhu and Umāsvāti hailed from Kusumapura near Patna. Umāsvāti was also the author of a *Kṣetrasamāsa* (collection of places) or *Jambūdvīpasamāsa*. This title belongs generally to a class of works popular among the Jainas, dealing with geography and mensuration. The cosmographico-geographical details, the elaborate specification of the dimensions of the different *dvīpas* and fantastic cosmological theories given in this class of works conceal at the same time important mathematical information for this early formative period. Finally, we have the name of Siddhasena, the Jaina in Varāhamihira's references, from which commentator Bhaṭṭotpala quoted a number of passages which show Siddhasena's interests in astronomy and mathematics.

Theory of Number

We have already mentioned the Jaina interest in the enumeration of large numbers. By the conception of *śīrṣaprahelikā* they suggested a number of the order of $8{,}400{,}000^{28}$. The Jaina terminology uses the word *sthāna* for the decimal place. As to names beyond thousand (*sahasra*), they prefer to proceed as follows: tens of thousands, hundreds of thousands, tens of thousands of thousands (*koṭi*), tens of *koṭi*, hundreds of *koṭi* and so on. In the Jaina system unity is not regarded as a number—*eko gaṇanāsaṃkhyā na upeti.* Numbers are classified into *oja* (odd) and *yugma* (even) as in the *Brāhmaṇa* system.

The whole range of numbers is again divided into three groups: *saṃkhyeya* (numerable), *asaṃkhyeya* (innumerable) and *ananta* (infinite). Each group is subdivided into three orders, e.g. the first group (numerable)—lowest, highest and intermediate; the second group (innumerable)—nearly innumerable, truly innumerable and innumerably innumerable; the third group (infinite)—nearly infinite, truly infinite and infinitely infinite. To form an idea of the highest numerable (*utkṛṣṭa saṃkhyeya*) of the first group, one is advised to count one by one white mustard seeds while filling with them a trough as large as the size of the Jambudvīpa of diameter 100,000 *yojana* and circumference 316,227 *yojana* 3 *gavyuti* 128 *dhanu* 13½ *aṅgula* and a little over.[a] In the same manner, one is to fill up with same seeds other troughs formed by the various oceans and islands mentioned in the Jaina cosmology, and count them one by one. The total number of mustard seeds will still be less than the highest numerable. All this is stated in the *Anuyogadvāra-sūtra*, which then continues to enumerate the number-groups of higher orders. If N be the highest numerable number as defined above, the higher groups may be represented as follows:

$$
\begin{array}{l}
(N+1) \;\ldots\; [(N+1)^2 - 1] \\
(N+1)^2 \;\ldots\; [(N+1)^4 - 1] \\
(N+1)^4 \;\ldots\; [(N+1)^8 - 1] \\
(N+1)^8 \;\ldots\; [(N+1)^{16} - 1] \\
(N+1)^{16} \ldots\; [(N+1)^{32} - 1] \\
(N+1)^{32} \ldots
\end{array}
$$

The highest numerable number of the Jainas reminds us of the Alef-zero of modern mathematics, and the Jaina imagination clearly went much further than that.

The Jainas are strongly believed to have possessed some kind of numeral symbols although it is not possible to say what these forms were. The *Samavāyāṅga-sūtra* (fourth century B.C.) and the *Prajñāpanā-sūtra* (second century B.C.) mention *aṅkalipi* and *gaṇitalipi* in connection with a list enumerating the different written characters. The two names suggest that in all probability different numeral forms were in use for different purposes, *aṅkalipi* being used in engraving and *gaṇitalipi* in ordinary writing.

[a] Datta (2), pp. 140–41.

Fundamental Operations, Factors

Umāsvāti mentions two methods of multiplication and division of which one is the ordinary method now generally followed and the other is a shorter operation carried out in successive stages by factors. The method of multiplication by factors reappears in the works of Brahmagupta and later authors. Śrīdhara, in his *Triśatikā*, develops the method of division by factors. The Jainas are found to have large and complicated arithmetical factors. One interesting feature is their frequent resort to approximation in dealing with mixed number. Whenever the fractional part is less than 1, it is neglected, but, when greater than $\frac{1}{2}$, it is replaced by unity. Thus 315089 is used in place of $315089\frac{218079}{630178}$ and 318315 in place of $318314\frac{553404}{636628}$. To indicate such approximation, expressions like *kiñcidviśeṣādhika* (a little more), *kiñcidviśeṣoṇa* (a little less) were used.

Mensuration

Rajju, as we have seen, was the Jaina name for geometry or mensuration, in which they closely followed the Vedic *śulbavids*. Of the many geometrical terms met with in their literature, the following may be mentioned: *sama-cakravāla*, *vṛtta* (circle), *vyāsārdha*, *viṣkambhārdha* (semi-diameter, radius), *jīva* (chord), *dhanupṛṣṭha* (arc), *sama-caturasra* (square), *sama-catuṣkoṇa* (even parallelogram), *caturasra* (quadrilateral), *āyata* (rectangle), *tryasra* (triangle), *viṣama-cakravāla*, *parimaṇḍala* (ellipse), *pratara* (plane), *ghana* (solid), *ghana-tryasra* (triangular pyramid), *ghana caturasra* (cube), *ghanāyata* (rectangular parallelepiped), *ghana vṛtta* (sphere), and so on.

A number of formulae concerning the mensuration of the circle were recorded by Umāsvāti in his *Tattvārthādhigama-sūtra-bhāṣya* and *Jambūdvīpa-samāsa*. These formulae are:

For a circle of diameter d, circumference p and area α,

$$p = \sqrt{10}\,.\,d$$

$$\alpha = \tfrac{1}{4}\,pd.$$

For the segment of a circle of arc a less than a semi-circle, chord c, sagitta or arrow s and diameter d,

$$c = \sqrt{4s(d-s)}$$

$$s = \tfrac{1}{2}(d-\sqrt{d^2-c^2})$$

$$a = \sqrt{6s^2+c^2}$$

$$d = \frac{1}{s}\left(s^2+\frac{c^2}{4}\right).$$

The relation of the arc a with respect to s and c is found in the works of Mahāvīra and Āryabhaṭa II. They have also given alternative formulae

varying only slightly in the numerical coefficient of s^2. Heron of Alexandria (third century A.D.) gives the relation as

$$a = \sqrt{4s^2+c^2}+\frac{s}{4}.$$

Shen Kua, in his *Meng Chhi Pi Than* (A.D. 1086), gives the formula for the sagitta as

$$a = c+\frac{2s^2}{d}.$$

The above-mentioned formulae, though found in a work by Umāsvāti, do not appear to have been discovered by him because some of these formulae were most likely utilized in earlier texts (*Sūryaprajñapti*, *Jambūdvīpa-prajñapti*) in the computations of the circumference of the Jambūdvīpa from its given diameter of 100,000 *yojana*, the linear dimensions of the seven parts in which Jambūdvīpa is divided, the dimensions of *Bhāratavarṣa* forming the southernmost segment of this *Dvīpa* and so on.

Value of π

In the relation given above of the circumference of a circle to its diameter, the value of π is shown to be $\sqrt{10}$. The astronomical tract *Sūrya-prajñapti* uses this value as also the less accurate one of 3. In the *Uttar-ādhyāyana-sūtra*, it is stated to be a little more than 3. But all medieval Jaina works systematically used $\sqrt{10}$ as the value of π in spite of a more accurate value having by then come into general use in all Brāhmaṇa astronomical and mathematical works.

Laws of Indices

The power series found in the Jaina works are limited to successive squares or square roots, e.g. a^2, $(a^2)^2$, $(a^4)^2$, $\ldots$ a^{2^n}, $(a^{\frac{1}{2}})$, $(a^{\frac{1}{2}})^{\frac{1}{2}}$, $(a^{\frac{1}{2}})^{\frac{1}{2}}$, $(a^{\frac{1}{2}})^{\frac{1}{2}}$, $\ldots (a^{1/n})^{\frac{1}{2}}$.
In other words,

first square of a means a^2
second square of a means $a^{2\times 2}$
third square of a means $a^{2\times 2\times 2}$
nth square of a means $a^{2\times 2\times 2\times \ldots \text{to } n \text{ term}}$.

In the *Anuyogadvāra-sūtra*, the world population is given to be a number obtainable by multiplying the sixth square of two by the fifth square, or a number which can be divided by two 96 times; it occupies twenty-nine places, or, according to another interpretation, lies between the twenty-fourth and the thirty-second place. According to the definition of the square terms, sixth square means 2^{2^6} or 2^{64} and fifth square means 2^{2^5} or 2^{32}. Therefore,

$$N = 2^{64}\times 2^{32} = 2^{96} = 79, 228, 162, 514, 264, 337, 593, 543, 950, 336.$$

Notice that the figure obtained occupies 29 places and is divisible by two 96 times. Here we have a clear indication of the application of the following laws of indices:

$$a^m \times a^n = a^{m+n}$$

$$(a^m)^n = a^{mn}$$

Permutations and Combinations

Statements of results presumably arrived at by the methods of permutations and combinations appear quite early in the Jaina literature. In the *Bhagavatī-sūtra*, *Anuyogadvāra-sūtra* and the *Jambūdvīpaprajñapti*, possible numbers of combinations out of n fundamental categories taken one at a time (*ekaka-saṃyoga*), two at a time (*dvika-saṃyoga*), three at a time (*trika-saṃyoga*) have been speculated upon, and possible number of selections out of a number of males, females and eunuchs, all calculations of various groups to be formed out of different senses, etc., have been given correctly. In the *Anuyogadvāra-sūtra*, the number of permutations of six things is given by $1 \times 2 \times 3 \times 4 \times 5 \times 6$ with further direction of deducting 2 to give the result less the direct and reverse orders. An English translation of the passage runs as follows:

> 'What is direct order? Dharmāstikāya, Adharmāstikāya, Ākāśāstikāya, Jīvāstikāya, Pudgalāstikāya and Samaya—this is the direct order. What is the reverse order? (Read the above from Samaya backwards). What is Ananupūrvī (mixed) order? In this series, the first term is unity, the common increase unity and the number of terms six. Multiply the terms one after the other and deduct two. This is the Ananupūrvī.'[a]

Śīlāṅka, a Jaina commentator of the ninth century A.D., reproduces from some ancient mathematical texts rules for permutations and combinations, with his own illustrations. One quotation, curiously enough, is in Ardhmaāgadhī. The rules are:

> 'Beginning with unity up to the number of terms, multiply continually the (natural) numbers. That should give the result as per calculations of permutations and combinations.'

That is

$$N = 1 . 2 . 3 \ldots (n-1)n.$$

Another rule for finding the actual spread (*prastārānayanopāya*) runs as follows:

> 'Divide the total number of permutations by the last term and the quotient by the next. These are to be placed one after the other by the side of the initial term in the calculations of permutations and combinations.'

[a] *Anu. Sū.*, 97; *see also* Chakravarti (G.), pp. 79–88.

The explanation of the rule after Śīlāṅka is as follows:

(1) The total number of permutations of r things taken all at a time

$$= 1 . 2 \ldots (r-1)r = r!$$

(2) The total number of permutations having a particular thing a_r for its initial digit $= \frac{r!}{r} = (r-1)!$

(3) The total number of permutations in which a_{r-1} will be next to a_r in (2) $= \frac{(r-1)!}{r-1} = (r-2)!$

Proceeding in this way, different permutations of things can be found out.

It must be noted, however, that meter and prosody offered a much more fertile field for the exploration of this branch of mathematics and the *chanda* (meter) specialists naturally enough led the way as already noticed before.

MATHEMATICS OF THE PERIOD SECOND TO EIGHTEENTH CENTURY A.D.

This period is characterized not only by the wealth of materials but also by the range, depth and quality of mathematical investigations which admirably suited the natural talents of this culture area. In the previous periods, the problems of architecture, particularly of the sacrificial altars, the intricacies of the science of language and commercial accounting stimulated the development of mathematics, in which also astronomy appears to play no mean part. But now the greatest inspiration for mathematics came doubtless from considerations of problems concerning the reckoning of time. As elsewhere, here in India too, a substantial part of mathematics developed as a sequel to astronomical advancement, and it is no accident that a sizeable part of post-Vedic mathematics has been found only in association with astronomical works. The relationship acted as a feedback process. Problems of accurate positioning of the heavenly bodies, description of their motions in longitudes, calculations and explanations of true positions from the mean, and several others, called for refinements in algebraic solutions of indeterminate problems, many arithmetical operations such as handling of large fractions, root extractions and led to the emergence of entirely new mathematical techniques of analysis, e.g. the methods of plane and spherical trigonometry. Mathematization of astronomy, in its turn, revolutionized astronomy on a scale by comparison with which the Vedic and the Jaina astronomy appeared almost primitive. As we have seen, the gestation period of the Siddhāntic astronomy, the result of such mathematization, may be limited to the first few centuries of the Christian era. The commercial factors also played a notable part,

particularly in the development of arithmetic. Expansion of trade and commerce, particularly with overseas countries, and the demands of an expansive economy doubtless had a beneficial effect on the progress of mathematics.

SOURCES

The Bakhshālī Manuscript (*third or fourth century A.D.*)

We open the discussion of the sources of this period with a manuscript whose date has been the subject of much controversy. The manuscript was discovered in 1881 in a small village called Bakhshālī near Peshawar now in Pakistan. Written on birch bark in *Śārada* script, the manuscript has survived in about 70 leaves, some of them in mere scraps. Hoernlé[a] who published a number of accounts of it placed it between the third and fourth century A.D., a dating with which Bühler, Cantor, Cajori, Datta and other scholars agreed. Kaye, who prepared photographic facsimiles and translation of the text with a long introduction, considered it to be a work not earlier than the twelfth century A.D. and even expressed doubt about its Indian origin. From a detailed study of its mathematical contents, Datta[b] established that the manuscript was a running commentary on an earlier work, in support of Hoernlé's view that 'there is every reason to believe that the Bakhshālī arithmetic is of a very earlier date than the manuscript in which it has come down to us'.

The manuscript is entirely a mathematical work containing rules, with illustrative examples and their solutions, for arithmetical, algebraic and geometrical operations. The major portion deals with arithmetic including fractions, square roots, progressions, income and expenditure, profit and loss, computation of gold, interest, rule of three and summation of complex series. The arithmetical notation generally employed is the decimal place-value notation. The algebraic operations discussed include simple and simultaneous linear equations, quadratic equations, surds, with interesting details as to plan of writing equations, unknown quantities, negative signs, the method of false positions and the like. Several problems relating to mensuration and miscellaneous subjects have also been dealt with.

In the selection of topics, methods of treatment, use of symbols, notations and terminology, the Bakhshālī manuscript presents several characteristic features by which it is distinguishable from other and more well-known Hindu works. While most of the topics discussed are met with more or less in contemporary or later works, significant omissions are indeterminate equations of the first degree, the Pellian equation and the geometry of shadows cast by a gnomon. These omissions have been interpreted as evidence of the more ancient nature of the work. Contrary to a majority of Hindu works, the method of exposition followed in it is detailed and generally comprises (*a*) the statement of the rule (*sūtra*), (*b*) examples

[a] Hoernlé (1), pp. 89–90; (2), pp. 33–48, 275–79.

[b] Datta (1), pp. 1–60.

(*udāharaṇa*) and (*c*) demonstration of the operation (*karaṇa*) of the rule or rules in the examples. Most of the original works we know are nothing but books of mathematical formulae rarely containing examples which are usually left to the commentators. Neither in the original nor in the commentaries it is expected of a Hindu tract to provide the demonstration or the rationale of the rules, which were the functions of the teachers belonging to the different schools to explain.

Āryabhaṭa I (*b.* A.D. 476)

In the history of mathematics, Āryabhaṭa occupies a special position not only by his appearance at the head of the Hindu mathematical renaissance but by the pattern and the tone set by him in mathematical investigations to be emulated by the generations of mathematicians to follow. His mathematical rules set forth in the highly condensed and sometimes cryptic form are given in the *Gītikāpāda* and the *Gaṇitapāda* sections of his *Āryabhaṭīya*, of which the remaining chapters deal with astronomy.

In his *Gītikāpāda*, Āryabhaṭa gives an account of an ingenious and peculiar alphabetical system invented by him of expressing numbers on the decimal place-value model. Tables of astronomical constants, trigonometrical sine tables and other numerical data are given in this new system. The *Gaṇitapāda* gives rules, among others, for the extraction of square and cube roots by the arithmetical method, areas of triangles, trapezium or any plane figure, circle, volumes of pyramid, sphere, value of π, arithmetical progression, summation of series, interest, rule of three, fractions, method of constructing sines by forming triangles and quadrilaterals in the quadrant of a circle, and indeterminate equations of the first degree. Āryabhaṭa gave the most accurate value of π as 3·1416 and used the formula

$$\sin (n+1)\alpha - \sin n\alpha = \sin n\alpha - \sin (n-1)\alpha - \frac{\sin n\alpha}{225}$$

for the construction of sine tables, a formula also used in the *Sūrya-siddhānta*. Rule for the solution of indeterminate equations of the first degree is found for the first time in his work although the germs of such equations are traceable to the *śulba-sūtras* as already noticed. This opened a favourite line of investigation among later Hindu mathematicians and developed into a new branch by its own right.

Āryabhaṭa was the founder of a mathematical-astronomical school. His commentators included, among others, Bhāskara I, Nīlakaṇṭha Somasutvan, Parameśvara, Someśvara, Sūryadeva and Yallaya. The first three, while following in the footsteps of their great master, also made important contributions of their own.

Bhāskara I (*c.* A.D. 600)

Well known for his *Mahābhāskarīya*, a shorter tract *Laghubhāskarīya* and a commentary (*Bhāṣya*) on the *Āryabhāṭīya*, Bhāskara I primarily

developed Āryabhaṭa's principles of astronomy. In mathematics, his main contribution lies in the field of indeterminate equations of the first degree, of which he dealt with many specific cases and gave several examples to explain their application in astronomy. He found a method to solve such equations with two remainders called *dvicchedagra*.[a]

Brahmagupta (c. A.D. 598)

George Sarton describes Brahmagupta as 'one of the greatest scientists of his race and the greatest of his time'. As the first mathematician to have attempted successfully the solution of the so-called Pellian equation he richly deserves such a reference. Although a critic of Āryabhaṭa, he follows the latter in introducing chapters on mathematics in his great astronomical treatise *Brāhmasphuṭa-siddhānta*. These two chapters are the twelfth called the *Gaṇitādhyāyaḥ* and the eighteenth the *Kuṭṭādhyāyaḥ*. The former is concerned with 20 arithmetical operations or logistics (*parikarma*), including square and cube roots, fractions, rules of three, five, seven, etc., barter, and eight determinations (*vyavahāra*), e.g. mixture, series, plane figures, excavation, stock, saw, mound and shadow. According to Brahmagupta's definition, a mathematician (*gaṇaka*) is one who has mastered distinctly and severally the 20 logistics beginning with addition and the eight determinations ending with the shadows. *Kuṭṭādhyāya* is the section on algebra and deals with the methods of pulverization in solving indeterminate equations of the first degree, linear equations with one or more unknowns, equations involving products of unknowns, square nature or indeterminate quadratic equations. The lemma he discovered for the solution of the last-named equations marked the culmination of his mathematical genius. Brahmagupta found an able commentator in Pṛthūdakasvāmin who lived in the ninth century A.D.; some other commentators were Āmarāja, Śrīdatta and Bhaṭṭotpala.

Mahāvīrācārya (c. A.D. 850)

Mahāvīra, the great Jaina mathematician, probably hailed from the Kanarese-speaking areas of south India and flourished during the reign of the Raṣṭrakuṭa King Amoghavarṣa Nṛpatuṅga (814–877). In keeping with the Jaina tradition, he studied mathematics for its own sake and not in association with astronomy as was the vogue with the Brāhmaṇa mathematicians. His *Gaṇita-sāra-saṃgraha* does not, therefore, form part of any astronomical treatise, but treats of mathematical problems in a more simple and direct manner. The copious illustrations characterizing his work also bear this impress. But he seems to be fully conversant with Brāhmaṇa mathematics and, in particular, with the works of Brahmagupta whose reputation as an authority was far and wide. In fact, he dealt with several of the problems which had engaged the attention of his illustrious

[a] Kuppanna Sastri, summary of contents to his *Mahābhāskarīya of Bhāskarācārya*, lxxvi.

predecessor and tried to improve upon them, often times with success, which shows that he was neither a mere compiler nor a commentator but an original investigator. From the fact that the manuscripts of his work and its commentaries have come down to us in Kanarese and in Telugu translations, Bhāskara II and other scholars in northern and central India do not refer to his work and it is not even mentioned in Sudhākara Dvivedi's *Gaṇakataraṅgiṇī*, it is reasonable to infer that his work was in circulation only in the south.

Gaṇita-sāra-saṃgraha is a work in nine chapters, dealing with operations with numbers excluding those of addition and subtraction which are taken for granted, squaring and cubing, determination of square and cube roots, summation of arithmetic and geometric series, fractions, rule of three, mensuration and algebra, including quadratic and indeterminate equations. His arithmetical operations are based on decimal place-value numeration. He mentions 24 notational places and uses word numerals as had been the established practice. He gives operation with zero, but erroneously states that a number divided by zero remains unchanged. Negative numbers are used. The process of summation of a series from which the first few terms are omitted is called by him *vyutkalita*. In his treatment of fractions he was the first among the Indian mathematicians to have used the method of lowest common multiple, called by him *niruddha*, in order to shorten the process. In mensuration, Mahāvīra's treatment is similar in spirit with that of either Brahmagupta or Bhāskara II, but much fuller and in certain cases a little more advanced. Like Brahmagupta, he gives the area of a quadrilateral as

$$\sqrt{(s-a)(s-b)(s-c)(s-d)}$$

but does not mention that it holds good only for a cyclic one. For the volume of a sphere, he gives an approximate rule as $\frac{9}{2}(\frac{1}{2}d)^3$ and an accurate one as $\frac{9}{10}\cdot\frac{9}{2}\cdot(\frac{1}{2}d)^3$, which makes π equal to 3·0375.

Mahāvīra gives two roots for quadratic equations and treats of simple and simultaneous indeterminate equations of the first degree.

Āryabhaṭa II (A.D. 950)

Well known as the author of *Mahāsiddhānta*, an astronomical compendium based more or less on the orthodox tradition of the *smṛtis*, Āryabhaṭa II discusses the favourite Hindu topic of indeterminate equations in a section called *Kuṭṭakādhyāya* in the 18th chapter of his book. Dealing mainly with indeterminate equations of the first degree, he improved upon the method by suggesting a shorter procedure. He has also given rules for solving quadratic equations along lines given previously by Āryabhaṭa I and Brahmagupta. Several arithmetical operations, such as the four fundamental operations, operations with zero, extraction of square and cube roots, rule of three and fractions, are also treated in this work.

Śrīdharācārya (c. A.D. 991) and Śrīpati (c. A.D. 1000)

Śrīdhara is referred to by Bhāskara II as a distinguished mathematician and is quoted by the latter in a number of places. We know of two arithmetical works by him—a fuller work under the title *Pāṭīgaṇita* and the other a smaller tract called *Triśatikā*, both of which have been edited, and of which a number of manuscripts also exist. His algebra is no longer extant, but is known from Bhāskara's references. The same arithmetical topics as are discussed by Brahmagupta, Mahāvīra and Bhāskara II are treated in the *Triśatikā*. For multiplication, he uses a new term *pratyutpanna* (reproduced) and discusses the *kapāṭa-sandhi* (door-junction, Gelosia) method which became very popular among later Hindu writers and was transmitted to the West through Arab works. We know from Bhāskara that Śrīdhara was the discoverer of a method of solving quadratic equations in which the two sides require to be multiplied by four times the coefficient of x^2. An application of this method is also preserved in his arithmetic. Śrīdhara's contemporary Śrīpati is well known for his arithmetic *Gaṇita-tilaka* commented upon by Siṃhatilaka Sūri in the thirteenth century.

Bhāskara II (c. A.D. 1114)

Bhāskara II represents the culminating point in mathematical and astronomical investigations in ancient and medieval India. In originality and innovations he probably ranks with Āryabhaṭa I and Brahmagupta. As a lucid expositor of abstruse mathematical and astronomical rules, he was probably unrivalled among his class in ancient and medieval India. His whole mathematical-astronomical work, *Siddhānta-śiromaṇi*, is divided into four parts, of which the first two the *Līlāvatī* and the *Bījagaṇita* deal with arithmetic and geometry and algebra respectively. The work in its entirety as well as in different parts are available in a large number of manuscripts which clearly indicate their popularity and wide distribution. This is also borne out by a large number of commentaries produced at different times, including Persian translations.

The *Līlāvatī* concerned with arithmetic and geometry is divided into the following chapters: (i) *paribhāṣā*, (ii) *saṅkalita-vyavakalita, varga, vargamūla, ghana, ghanamūla, śūnyaparikarma*, etc., (iii) *vyastavidhi, trairāśika*, (iv) *miśraka-vyavahāra*, (v) *śreḍhī-vyavahāra*, (vi) *kṣetra-vyavahāra*, (vii) *khāta-vyavahāra*, (viii) *citi*, (ix) *krakaca-vyavahāra*, (x) *rāśi-vyavahāra*, (xi) *chāyā-vyavahāra*, (xii) *kuṭṭaka* and (xiii) *aṅkapāśa-vyavahāra*. The topics in which the chapters of the *vījagaṇita* (algebra) are arranged are the following: (i) *ghana-vivaraṇa*, (ii) *śūnya-vivaraṇa*, (iii) *varṇa-vivaraṇa*, (iv) *karaṇī-vivaraṇa*, (v) *kuṭṭaka-vivaraṇa*, (vi) *varga-vivaraṇa*, (vii) *ekavarṇa-samīkaraṇa*, (viii) *madhyamāharaṇa*, (ix) *anekavarṇa-samīkaraṇa*, (x) *anekavarṇa-madhyamāharaṇa* and (xi) *bhāvita*.

Both in his arithmetic and algebra, we find a full discussion on operations with zero in which the result of division of a finite number by zero is correctly given. His arithmetic does not contain further novelties than

what are found in the works of his predecessors, except that the rules are more lucid and accompanied by many examples. His algebra is characterized by anticipation of the modern theory concerning the sign convention, use of letters to denote unknown quantities and detailed discussions of several types of equations, including indeterminate equations of the first and second degree. The cyclic method (*cakravāla*) of solving the Pellian equations, $Nx^2+1 = y^2$, $Nx^2+c = y^2$, described by Hankel as 'the finest thing achieved in the theory of numbers before Lagrange' is due to him. His *tātkālika* method of analysis contains the germ of modern calculus. From consideration of right-angled triangles and regular polygons up to 384 sides, he found the value of π as $\frac{3927}{1250}$ and also $\frac{754}{240} = 3{\cdot}141666$. Some of his findings will be further discussed in what follows.

Nārāyaṇa (*c.* A.D. 1350)

There are several authors of the name of Nārāyaṇa of whom four attained distinction in mathematics, astronomy and astrology. The most important of them as a mathematician was Nārāyaṇa Paṇḍita, son of Nṛsiṃha Daivajña, who flourished during the reign of Firuz Shah (1351–1388). He composed two works, one on arithmetic the *Gaṇitakaumudī* and the other on algebra the *Bījagaṇitāvataṃsa*. He was clearly influenced by Bhāskara II; nevertheless, his works attracted wide notice and became quite popular as is evidenced by the existence of a number of commentaries by Jñānarāja, Sūryadāsa, Gaṇeśa and others. His algebra is a work of greater merit and is divided into two parts: (i) laws of signs, arithmetic of zero, operations with unknown quantities, surds, pulverizer, square nature, cyclic method, and (ii) four kinds of analysis, simple equations. In his discussions, he clearly follows Āryabhaṭa, Brahmagupta, Śrīdhara and Bhāskara.

The Work of the Commentators

The centuries following the time of Bhāskara II largely belonged to the commentators. This is not to suggest that occasionally works of originality were not produced after Bhāskara II or that the period up to his time was only one of original investigators. Brahmagupta's scholiast Pṛthūdakasvāmin flourished in the ninth century A.D. and was a distinguished scholar; as to works of merit other than commentaries we have already noticed Nārāyaṇa Paṇḍita and there were many others. However, commentaries on mathematical works in a fairly steady stream began to appear from the fifteenth century. Gaṅgādhara (*c.* A.D. 1420), an inhabitant of Gujarat, wrote a commentary on the *Līlāvatī* with expositions from Bhāskara's *Bījagaṇita* as well. Colebroke used it in the translation of the *Līlāvatī* in his *Algebra*. Gaṅgādhara's brother, Viṣṇu Paṇḍita, wrote an arithmetic called *Gaṇitasāra* on the model of Śrīdhara from whom passages were quoted. The greatest commentator of the fifteenth century was Parameśvara (*c.* A.D. 1430), a Nampūtiri Brāhmaṇa from Kerala, who commented both on astronomical

and mathematical works and also wrote a few original tracts. His commentaries include *Bhaṭadīpikā* on Āryabhaṭa, *Karmadīpikā* and *Siddhāntadīpikā* on Bhāskara I's works, the *Vivaraṇa* or *Līlāvatī-vyākhyā* on Bhāskara II. His other commentaries and tracts mostly concern astronomy.

During the fifteenth and the following centuries, south India, particularly the Malayalam-speaking areas, developed active centres for astronomical-mathematical studies. These schools produced such works as *Karaṇapaddhati*, *Gaṇitayuktibhāṣā* and *Sadratnamālā* which, among others, discussed for the first time trigonometrical sine, cosine, tan and π series and gave rules for them. While their period of composition has been inferred from internal evidence, nothing is known about their authors. *Karaṇapaddhati* was written by a certain Brahmin of the village of Śivapura. *Gaṇitayuktibhāṣā* is an anonymous work in Malayalam on arithmetic and mensuration primarily aimed at explaining the mathematical portion of Nīlakaṇṭha's *Tantrasaṃgraha*. This Nīlakaṇṭha Somasutvan (A.D. 1465–1545), who wrote the best commentary on the *Āryabhaṭīya*, also composed several independent works, including *Tantrasaṃgraha*, and was widely known in the south.

About this time in western, central and northern India we hear of a number of distinguished Brāhmaṇa families zealously pursuing astronomical and mathematical studies and producing gloss, commentaries and other explanatory works. At Pārthapura at the confluence of the Godāvarī and the Vidarbha there flourished Jñānarāja (*c.* A.D. 1503) who wrote a commentary on Bhāskara's algebra, but was more well known for his *Siddhāntasundara*, an astronomical compilation. His son Sūryadāsa (*c.* A.D. 1541) composed the *Sūryaprakāśa* and the *Gaṇitāmṛtakūpikā*, the former a commentary on Bhāskara's algebra and the latter on his arithmetic; Jñānarāja's disciple Ḍhuṇḍhirāja (A.D. 1541) was also an able commentator on astronomical works.

Gaṇeśa Daivajña (*c.* 1507), author of the popular astronomical work *Grahalāghava*, hailed from Nandīgrām on the Arabian Sea about 40 miles from Bombay (Colebrooke put it 65 miles west of Daulatabad). His *Buddhivilāsinī* on the *Līlāvatī*, accompanied by copious illustrations, was one of the best expositions of this arithmetical classic. His father Keśava, nephew Nṛsiṃha and cousin Lakṣmīdāsa were all accomplished astronomers. Another family of astronomers in Mahārāṣṭra was that of Divākara of Golagrām (lat. 18° N, long. 78° E) on the northern bank of the Godāvarī. Divākara was a disciple of Gaṇeśa Daivajña and in turn trained his five sons, Kṛṣṇa (b. A.D. 1561), Viṣṇu (b. A.D. 1566), Mallāri (b. A.D. 1571), Keśava and Viśvanātha (b. A.D. 1578), in astronomy. All of them, particularly Mallāri and Viśvanātha, turned out in time to be able commentators. This tradition was transmitted and fully maintained for a few generations through Kṛṣṇa's son Nṛsiṃha (b. A.D. 1586) and his four sons, Divākara, Kamalākara (*c.* A.D. 1616), Gopinātha and Raṅganātha (*c.* A.D. 1640). Kamalākara, the author of *Siddhāntatattvaviveka* (A.D. 1658), besides being well versed in Hindu astronomy and mathematics also picked up some Arabic and

Persian astronomy and mathematics. Some passages from Euclid's *Elements* as well as a few astronomical elements from Persian sources were incorporated in his *Siddhānta* and on the basis of these he ventured to criticize Bhāskara's astronomy. His younger brother Raṅganātha composed, among others, a commentary *Mitabhāṣiṇī* on the *Līlāvatī.*

Vallāla's ancestors, well known for their interest in astronomy and mathematics, had their original home in Elachpur in Madhya Pradeśa. Of his five sons, Kṛṣṇa Daivajña (*c.* A.D. 1565) and Raṅganātha (*c.* A.D. 1573) made their mark in mathematics and astronomy. Kṛṣṇa was a disciple of Viṣṇu, son of Divākara of Golagrām, and rose to be the chief astronomer of Emperor Jahangir. He wrote an excellent commentary *Navāṅkura* on Bhāskara's *Bījagaṇita* and another work entitled *Kalpalatāvatāra* on the *Līlāvatī.* His brother Raṅganātha's fame was based on his excellent exposition of the *Sūrya-siddhānta* in his commentary *Gūḍhārthaprakāśaka.* Raṅganātha's son Munīśvara (b. A.D. 1603), a great admirer of Bhāskara II, wrote a commentary *Nisṛṣṭārthadūti* on *Līlāvatī,* composed an arithmetic entitled *Pāṭīsāra* and a gloss *Marīci* on the *Siddhānta-śiromaṇi.* A contemporary of Kamalākara, he attacked the latter for his criticism of Bhāskara's astronomy.

Exchange of Mathematical Learning between the Exponents of Sanskrit and those of Arabic and Persian

We have referred to Kamalākara's acquaintance with Arabic and Persian astronomy and mathematics. The mutual process of Hindu scholars assimilating Arabic and Persian learning and Muhammadan scholars digesting, reproducing and translating Hindu scientific works had of course started much earlier. We have already noticed the effort of Mahendra Sūrī in the fourteenth century to incorporate Persian knowledge in his *Yantrarāja,* of which a commentary was produced by Malayendu Sūrī in the seventeenth century. Nīlakaṇṭha Jyotirvid who flourished in the court of Akbar compiled a *Tajik* work in which a large number of Persian technical terms were introduced. At Akbar's command, Faizī prepared a Persian version of the *Līlāvatī* in A.D. 1587. In A.D. 1634, during the reign of Shah Jahan, Ata Ullah Rashidi translated Bhāskara's *Bījagaṇita* into Persian.

Such cross-fertilization of scientific learning between the exponents of Hindu scholarship on the one hand and those of Arabic and Persian scholarship on the other reached its highest point in the astronomical efforts of Mahārājā Sawāi Jai Sing II of Jaipur (1686–1743). A distinguished soldier, statesman and politician, Jai Sing was equally distinguished as an astronomer and mathematician, of which we have already spoken. At his orders, Jagannātha (b. A.D. 1652), the well-known astronomer of his court, translated Euclid's *Elements* into Sanskrit under the title *Rekhāgaṇita* from the Arabic version *Taḥrīr-u-Uqlidas* by Nāṣīr-al-dīn aṭ-Ṭūsī. We have already referred to his another laudable effort in translating Ptolemy's *Almagest* under the title *Samrāṭ-siddhānta,* thus making available for the

first time in Sanskrit the entirety of this great Alexandrian Greek's mathematical-astronomical classic. Jagannātha and other paṇḍits in the employ of Jai Sing must have prepared translations of several other Arabic and European works on mathematics. We know from Hunter that when he met a grandson of Jai Sing's principal assistant (Jagannātha), he saw in his possession the translation into Sanskrit of several European works including *Elements*, a treatise on plane and spherical trigonometry, and tract on the construction and use of logarithms of which the inventor was said to be one Don Juan Napier.[a] However, there now exist manuscripts of a work entitled *Ukārākhya Grantha* by one Nayanasukhopādhyāya (*c*. A.D. 1730), which deals with spherical geometry and is probably a translation of an Arabic work.[b]

MATHEMATICAL CONTENTS OF THE POST-VEDIC PERIOD

ARITHMETIC

Decimal Place-value Numeration

It is well known that the development of arithmetic depended largely upon the mode of expressing number. Before the adoption of numerals with positive values, its progress was everywhere slow and halting. The early advantage, skill and excellence attained by the Indians in this branch has been due primarily to their discovery of the decimal place-value concept and notation, that is the system of expressing any number with the help of either groups of words or 10 digits including zero having place-value in multiples of 10. Mathematicians and orientalists are generally agreed that the system with zero originated in India and thence travelled to other parts of Europe. 'Our numerals and the use of zero', observed Sarton, 'were invented by the Hindus and transmitted to us by the Arabs (hence the name Arabic numerals which we often give them).'[c] In the beginning of the present century a few scholars, notably George Rusby Kaye and Baron Carra de Vaux, disputed the general view by questioning the reliability of Indian as well as Arabic literary traditions on grounds of chronological uncertainty. Their objections and criticisms have been adequately answered by both mathematicians and orientalists such as Ruska, Datta, Ganguly, Das and Clark. But the knowledge derived from the study during the last 30 years or so of Babylonian mathematical cuneiform texts by Neugebauer, Sachs and others and from recent studies of Chinese mathematics by Needham and his co-workers calls for a re-examination of the question of the origin and development of the system in India. The mathematical cuneiform texts of the old Babylonian period (1600 B.C.) provide evidence of the use of a system of numeration based on place-value notation on the sexagesimal scale. Neugebauer believes that the idea spread to the Greeks and the Hindus and the latter contributed the final

[a] Hunter, p. 209.
[b] Sen (S. N.) (5), p. 153.
[c] Sarton (2), p. 151.

step of changing the scale from the sexagesimal to the decimal. Needham claims that the numeral forms and the method of number writing, as contained in the Shang oracle bone (1400–1100 B.C.), were based on decimal place-value idea. As to the discovery of zero, he credits South-East Asia (Indo-China, Java) for it inasmuch as the Hindu culture there 'met the southern zone of the culture of the Chinese'. The 'emptiness' of Taoist mysticism no less than the 'void' of Indian philosophy, Needham thinks, contributed to the invention of a symbol for zero.

Decimal Basis of Numeration and Word-numerals

We have seen that from the Vedic times the basis of numeration in India has been 10. There are ample references to this in the literature of the Brāhmaṇas, the Jainas and the Buddhists which, moreover, reveal a peculiar interest in the enumeration and naming of large numbers. The word-numerals and their use in a decimal place-value arrangement represent another unique development in India. This system was designed particularly to compress a large mass of numerical data in versified mathematical texts. The word-names were selected from consideration of their association with number. Thus '0' meaning 'emptiness', 'void', etc., was denoted by *kha*, *ākāśa*, *ambara*, *śūnya* and their various synonyms; 1 by earth synonyms, e.g. *kṣiti*, *dharā*, *pṛthivī*, moon synonyms *indu*, *candra*, etc.; 2 by *yama*, *aśvin*, *dasra*, *akṣi*; 3 by *rāma*, *guṇa*, *agni*, etc.; 4 by *veda*, *samudra*, etc.; and so on. Coining of word-numerals may be traced to the *Ṛgveda* and their use without place-value has been found in the *Brāhmaṇas*, *Vedāṅga Jyotiṣa* and some *sūtra* texts. Their use in a decimal system appears in the *Agni Purāṇa* and in the *Pañca-siddhāntikā*. A few examples from the *Pañca-siddhāntikā* are given in Table 3.1.

In these examples, the word-numerals, although to be read in the verse from left to write for the sake of meter, are to be arranged from right to

TABLE 3.1

1	2	3	4	5	6	7	7	6	5	4	3	2	1
nava	*- vasu*	*- guṇa*	*- rasa*	*- rasāḥ*					6	6	3	8	9
śara	*- nava*	*- kha*	*- indriya*	*- arṇava*	*- āśāḥ*		1	0	4	5	0	9	5
muni	*- yama*	*- yama*	*- dvi*							2	2	2	7
śūnya	*- dvi*	*- pañca*	*- yama*							2	5	2	0
svara	*- eka*	*- pakṣa*	*- ambara*	*- svara*	*- ṛtu*			6	7	0	2	1	7
rasa	*- viṣaya*	*- guṇa*	*- ambara*	*- ṛtu*	*- yama*	*- pakṣa*	2	2	6	0	3	5	6

left, that is in the order of unit, ten, hundred, etc., in accordance with the principle—*aṅkānāṃ vāmato gatiḥ* (numerals move to the left)—for

ascertaining their numerical meaning. Notice also how the word *yama* or *pakṣa*, meaning 2 when used in the unit place, represents the numbers 20, 200, 2000, 200000 and 2000000 when used in the 2nd, 3rd, 4th, 6th and 7th place respectively.

The word-numerals found extensive use in inscriptions and even travelled to foreign countries along with the Hindu colonizers. The following are some of the typical examples of such inscriptions found in Cambodia, Champa and Java:

(i) Stone inscription of Phnom Bàyàṅ, Cambodia (A.D. 604):

6 2 5
rasa - dasra - śaraiś - śakendravarṣe = in the year 526 of the śaka king, that is 526 śaka.

(ii) Stone inscription of Mī-son, Champa (A.D. 609):

9 7 5
nava - saptatyuttarapañca varṣaśatātīta śaka-vanīndra - kālaparimāṇam = in the śaka epoch 579, that is 579 śaka.

(iii) Stone inscription of Kangal, Java (A.D. 732):

4 5 6
śākendre tigate śrutīndriyarasairaṅgikṛte vatsare = in the year of the śaka king expressed by the number 654, that is 654 śaka.

We shall presently see that the above inscriptional records were soon followed by numerals with zero arranged according to decimal place to express śaka dates.

Alphabetical System

In the section *Daśagītikā* of the *Āryabhaṭīya* is recorded a novel alphabetical system of expressing numbers with the help of consonants and vowels, based on the decimal place-value principle. An English version of the relevant verse runs as follows:

> 'The *varga* letters beginning with *ka* (are to be used) in the *varga* (square) places and the *avarga* letters in the *avarga* (non-square) places; *ya* equals the sum *ṅa* and *ma*. The nine vowels (are to be used) in two nine places, *varga* (square) and *avarga* (non-square). (Those) nine (vowels should be used) in higher places in a similar manner.'[a]

In this system, 25 *varga* letters from *k* to *m* have values from 1 to 25 and seven *avarga* letters from *y* to *h* have values from 3 to 10. Their places are governed by nine vowels *a* to *au*, distinction between short and long vowels being disregarded. Thus the expression *khyughṛ* means

$$\begin{aligned} khyugh\d{r} &= khu + yu + gh\d{r} \\ &= 2\times10^4+3\times10^5+4\times10^6 \\ &= 4{,}320{,}000 \end{aligned}$$

[a] *Ā. Daśa. paribhāṣā* stanza.

Despite great ingenuity displayed, the system was not without limitations and ultimately failed to receive widespread use, except among the adherents of the Āryabhaṭa school.

About the same time a similar but somewhat improved system of alphabetical notations, called *kaṭapayādi*, was developed and used in mathematical-astronomical texts. The system employs place-value and was probably known to Āryabhaṭa. It was used by Bhāskara I, Āryabhaṭa II, Parameśvara and others. Its use is also found in the *Jaiminī-sūtras* of uncertain date.

Literary References

Literary works contain several references to the use of zero before its appearance in inscriptional records. There zero is expressed by such terms as 'emptiness', 'void', etc. Piṅgala's *Chandaḥ-sūtra* mentions zero in the rules for calculating the number of long and short syllables in a meter of n syllables. In the Bakhshālī manuscript we meet with a symbol 0 which has been called *śūnya* (emptiness, void). This has been interpreted by Hoernlé and Kaye as a symbol for the unknown quantity from its use in algebraic operations. But the symbol has also been used in the same text in connection with the decimal arithmetical notation. Datta[a] has interpreted the symbol as a true representation of zero whose use for an unknown quantity is also understandable if by it we mean the absence of a quantity which should be there. In the Kashmirian *Atharvaveda*, zero is represented by a dot. The Sanskrit name for this zero-dot is *śūnya-vindu* as is clearly stated in Subandhu's *Vāsavadattā* (*c*. A.D. 600).

In the Śrīvijaya inscriptions of Palembang in Sumatra a dot is used in writing the 'zero' of the number 605. The early Arab writers on Hindu numerals system used a dot to represent zero, for which the Arabic term is *aṣ-ṣifr* or *ṣi-fr*. It is easy to see how from such Arabic words Latin words for zero, e.g. *ciffre, ziffre, zephyrum, cyfra, tziphra*, etc., were derived. Sacrobosco used the word *figura nihili* in the full sense of void, emptiness, as the Hindus had done before.

Operations with Zero

More important is the early realization by the Indian mathematicians of the various operations with zero in the mathematical sense. From Brahmagupta onwards, mathematical works systematically give rules of operations with zero as follows:

$$a-a=0;\quad a\pm 0=a;\quad 0\pm a=\pm a;\quad 0\times(\pm a)=0$$

$$0\times 0=0;\quad \frac{0}{a}=0;\quad \frac{\pm a}{0}=(\textit{kha-cheda})$$

The correct interpretation of the last operation was due to Bhāskara II.

[a] Datta (1), pp. 23–25.

TABLE 3.2

Numerals without place-value

	Kharoṣṭhī	Brāhmī		
	ŚAKA PARTHIAN KUṢĀNA	AŚOKA Inscriptions	NĀNĀGHAT Inscriptions	NĀSIK Inscriptions
1	I	I	—	—
2	II	II	=	=
3	III			≡
4	X	+	¥ ¥	¥ 𐑋
5	IX			ꝩ ꝭ
6	IIX	ℓ ɕ	φ	ч
7	IIIX		?	7
8	XX			ч ?
9			?	?
10	7		α α α	α α
20	3		o	θ
30				
40	33			Z
50	733	G.ე		
60	333		ঀ	
70	7333			ϒ

	Kharoṣṭhī	Brāhmī		
	ŚAKA PARTHIAN KUṢĀNA	AŚOKA Inscriptions	NĀNĀGHAT Inscriptions	NĀSIK Inscriptions
80	3333		ϖ	
90				
100	ʈ I		ঽ	ๆ
200	ʔ II	ɣ ʎ ɾ ꝭ	ঽɾ	ๆɾ
300	ʔ III		ঽɾ	
400			ঽꝭ	
500				ๆꝭ
700			ঽη	
1000			T	ᶋ
2000				ᶋ
3000				ᶋ
4000			T¥	ᶋ¥
6000			Tφ	
8000				ᶋч
10,000			Tα	
20,000			Tο	

Epigraphic and Inscriptional Records

The epigraphic records of numeral notations in India, of both non-place- and place-value, are summarized in Tables 3.2 and 3.3.

The Kharoṣṭhī numerals found in the Aśokan, Śaka, Parthian and Kuṣāṇa inscriptions of the period from the fourth century B.C. to the second century A.D. are shown in column 2 of Table 3.2. Strokes and crosses were used for the first nine digits and symbols for 10 and its higher powers. With strokes and crosses and the sign 7 for 10, the numbers were built up to 99 on additive principle. The multiplicative principle was used in developing symbols for 100 and its multiples 2, 3, etc., up to 9. No sign for 1000 has revealed itself so far. Thus

100	200	300
ʈ I	ʔ II	ʔ III

TABLE 3.3
Numerals with place-value

Value	GURJARA Grants (A D 595)	BĀUKA Inscriptions (A D 837)	GWALIOR Inscriptions (Bhojadeva) (A D 870)	GWALIOR Inscriptions (Bhojadeva) (A.D. 876)	MAHĪPĀLA Inscriptions (A D. 917)
1			[illegible]	[illegible]	
2			[illegible]		
3	[illegible]		[illegible]	[illegible]	
4	[illegible]	[illegible]	[illegible]		[illegible]
5		[illegible]	[illegible] [illegible]	[illegible]	[illegible]
6	[illegible]		[illegible]		
7			[illegible] [illegible]	[illegible]	[illegible] [illegible]
8			[illegible] [illegible]	[illegible]	
9		[illegible]	[illegible]	[illegible]	[illegible]
0			o	o	o

Intermediate numbers were written on the additive principle as follows:

22	74	122	274
II3	X7333	II3TI	X7333ʕII
(2 + 20)	(4 + 70)	(2+20+ 100)	(4+ 70+ 200)

Numeral symbols were used on the left-hand side in developing numbers on the additive principle and on the right-hand side for those on the multiplicative principle.

The Brāhmī numerals (columns 3–5, Table 3.2) are more sophisticated in their forms and use separate signs for the digits 1, 4 to 9 and for numbers 10 and its multiples up to 90 and for 100, 1000, etc. Multiples of 100 and 1000 up to 9 were derived on the multiplicative principle, as in the case of the Kharoṣṭhī for multiples of 100. A few examples are given below:

Nānāghat

100	400	700	1000	4000	6000	10,000	20,000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Nāsik

100	500	1000	2000	4000	8000

Table 3.3 shows numeral forms used in decimal place-value system and found in stone as well as in grant-plate inscriptions. A few typical forms have been chosen from more than 30 inscriptional records of such numeral notations that have come to light. A circular symbol for zero appears in the Gwalior inscription (column 4) pertaining to the reign of Bhojadeva in which the verses were numbered from 1 to 26 in decimal figures. In another Gwalior inscription (column 5), the date 933 in Vikrama Samvat and the numbers 270, 187 and 50 were given in decimal place-value system. The Gwalior inscriptions provide the earliest palaeographic record so far known in India of the use of zero in a decimal place-value system.

For palaeographic records of still earlier dates we have to turn to the Hindu colonies of South-East Asia. Decimal place-value numerals with a point symbol (*śūnya-vindu*) as well as a circular symbol for zero have been discovered in three seventh-century inscriptions—two at Palembang in Sumatra and one in Banka.[a] These give the Śaka dates 605, 606 and 608 in figures. Another old Śrīvijaya inscription found in Saṃbór gives the Śaka date 605 in the same way. Drawings of some of these figures are given below:

605	608	735
Khmère inscription of Saṃbór	Inscription of Kota Kapur (Banka)	Inscription of PO Nagar (Champa)

In Java, two fragments of inscriptions have been found in Dinaya, which express the same date in word-numerals as well as in figures having decimal place-value. The Śaka date 682 is given as *nayanavasurasa* and also in figures.

From what we know about the development of word-numerals in ancient India, their appearance later on in monumental inscriptions in association with Śaka dates and their subsequent replacement by figures with zero in Hindu culture areas of South-East Asia can only lead to the conclusion that the numerals with zero had originated in the parent country and thence travelled to South-East Asia with the Hindu colonizers. Coedès also arrived at the same conclusion when he said that 'their (of the numerals with zero) use in the Indian colonies at an old date is clearly in favour of their existence in India at a date older still' (English translation of

[a] Coedès, pp. 323–28.

the French version). It is therefore difficult to agree with Needham[a] that the Chinese decimal place-value system and the emptiness of the Taoist mysticism might have stimulated the discovery of zero in South-East Asia.

Hindu Originality

The Babylonian origin of the place-value system now appears beyond doubt. It is immaterial that they chose a sexagesimal scale. But whether the Hindu decimal place-value was derived from the Babylonian sexagesimal place-value must remain a matter of conjecture only. The discovery of cuneiform inscriptions of the Hittite Kings of Mitanni in Cappadocia (fifteenth or fourteenth century B.C.) and the archaeological finds from Ur, Harappa and Mohenjo-daro have established India's relations with Western Asia from the third millennium B.C. There are stray instances of Babylonian sexagesimal parameters appearing in Indian astronomical texts. But the fact that the sexagesimal system was never generally adopted in India, the very ancient and long Indian tradition handed down from the Vedic times of giving decimal place-names and the various experiments of expressing numbers on a decimal place-value plan are still valid grounds for believing in an independent Indian origin of the system with zero.

New Arithmetic

The development of the place-value system meant the evolution of a new kind of arithmetic which Sarton described as a 'medieval novelty'. This medieval novelty represented by algorism, the term used to mean arithmetic, came to Europe largely through Arabic translations of, and works based on, Indian treatises and influenced in no small measure European mathematical renaissance.

Multiplication, Division

About the four fundamental operations of addition, subtraction, multiplication and division, the first two need not be considered. Most of the arithmetical works give four and some five or more methods of multiplication, of which the frequently occurring ones are *kapāṭa-sandhi, tastha, rūpa-vibhāga, sthāna-vibhāga, iṣṭa-gaṇita* and the *gelosia* method. The latter is sometimes included also under *kapāṭa-sandhi.* The first method was in common use, of which Śrīdhara gives the rule as follows: 'Place the multiplicand below the multiplier and multiply successively in the direct or the reverse order; move the multiplier after each operation; this is called *kapāṭa-sandhi.*' This is the same as the modern method followed generally in elementary schools with the multiplier being placed under the multiplicand.

The *gelosia* or grating method is first noted in Gaṇeśa's *Buddhivilāsinī.* Gaṇeśa explained it with reference to an example of the *Līlāvatī*[b] as

[a] Needham, III, p. 12.

[b] Colebrooke's translation of the *Līlāvatī* with notes by H. C. Banerjee, p. 7.

shown in Fig. 3.13. The *kapāṭa-sandhi* method is given by such Arab mathematicians as al-Khwārizmī (A.D. 825), al-Nasavī (*c.* A.D. 1025), al-Qalasādī (*c.* A.D. 1475) and several others. From al-Nasavī's reference to the method as *ta'rikh al-hindī* and *al-amal al-hindī*, Indian transmission is indicated. The *gelosia*, also known as the method of the quadrilateral, the square or the cell, appears among the Arabs and later on among the Latin European mathematicians such as Pacioli (*c.* A.D. 1464), Tartaglia (*c.* 1545). On the question of its origin and transmission, Smith observed: 'It was very likely developed first in India, for it appears in Gaṇeśa's commentary on the *Līlāvatī* and in other Hindu works. From India it seems to have moved northward to China, appearing there in an arithmetic of 1593. It also found its way into the Arab and Persian works, where it was the favourite method for many generations.'[a]

FIG. 3.13. *Gelosia* method.

The operation of division, particularly the long one, was considered the most difficult of the fundamental operations in Europe even as late as the fifteenth century. We have Luca Pacioli's remark, in Smith's quotation, that 'if a man can divide well, everything else is easy, for all the rest is involved therein'. Modern method of division appears in the form of rules in the works of Mahāvīra, Śrīdhara, Āryabhaṭa II and later writers, but that does not imply lack of the knowledge of it before the ninth century. Āryabhaṭa I and Brahmagupta, although they refrained from discussing the method, clearly showed easy acquaintance with it in their operations of extracting the square and cube roots of large numbers as we shall presently see. A method of division by removing common factors was probably known to early Jaina writers.

Square and Cube Roots

The modern arithmetical methods of extracting the square and cube roots of any number appear from Āryabhaṭa I onwards. Brahmagupta, Mahāvīra, Śrīdhara, Bhāskara II, Kamalākara and others have all given the same rules with varying degrees of clarification, and with examples by some. Here is Āryabhaṭa I's rule for the square root extraction:[b]

bhāgaṃ haredavargānnityaṃ dviguṇena vargamūlena |
vargādvarge śuddhe labdhaṃ sthānāntare mūlam ||

---

[a] Smith (D. E.), II, pp. 115–16.

[b] *Ā. Gaṇita.*, 4.

which means:

> 'One shall always divide the non-square place (*avarga*) by twice the square root of the (preceding) square place, then subtract the square (of the quotient) from the (next) square place; the quotient placed at the next place is the root.'

Following Parameśvara's commentary, the number whose square root is to be determined is to be divided into two categories of places, square (*varga*) and non-square (*avarga*) places. From the last square or odd place, counting from right, one should subtract the square of the highest root permissible. This root is to be set apart. The next number in the even or non-square place on being placed after the previous remainder should be divided by twice the root thus set apart. The square of the quotient obtained is to be subtracted from the next square place. The quotient is a root for the next operation and should be placed in a row after the previous one. This is illustrated in the following example:[a]

1 1̊ 9̄ 0̊ 2̄ 5̊ (3 = root of a number nearest the last odd place

$3^2 =$ 9

Twice the root, $2\times 3 = 6$) 2 9 (4 = quotient or next digit of root
2 4
5 0

Square of the quotient to be subtracted from the next square place, $4^2 =$ 1 6

Twice the root, $2\times 34 = 68$) 3 4 2 (5 = quotient or next digit of root
3 4 0
2 5

Square of the quotient, $5^2 =$ 2 5
0

The required square root = 345

For the cube root extraction, we give Brahmagupta's rule which is the same as that given by Āryabhaṭa I before him.

> 'The divisor for the second non-cubic (digit) is thrice the square of the cubic root. The square of the quotient, multiplied by three and by the preceding, must be subtracted from the next (non-cubic); and the cube from the cubic (digit): the root (is found)' (Translation after Colebrooke (2)). The steps are explained in the following example:

[a] Sen (S. N.) (2), pp. 306–7.

3 4 9 6 5 7 8 3 (3 = root of the number nearest the last cubic place

$3^3 =$ 2 7

Thrice square of root, $3 \times 3^2 = 27$) 7 9 (2 = quotient or next digit of root
5 4

Square of quotient multiplied by thrice the previous root, $2^2 \times 3 \times 3 =$
2 5 6
3 6

2 2 0 5

Cube of the quotient, $2^3 =$ 8

Thrice square of root, $3 \times 32^2 = 3072$) 2 1 9 7 7 (7 = quotient or next digit of root
2 1 5 0 4

Square of quotient multiplied by thrice the previous root, $7^2 \times 3 \times 32 =$
4 7 3 8
4 7 0 4

3 4 3

Cube of the quotient, $7^3 =$ 3 4 3

0

The required cube root = 327

Special importance attaches to Āryabhaṭa's rules for the extraction of the square and the cubic root because these, through the use of square, non-square, cubic and non-cubic places and by the procedures laid down, clearly indicate the use of decimal place-value notation with zero in Āryabhaṭa's time and possibly for a long time before him. These arithmetical operations were the direct consequence of the decimal place-value system. In Europe, these modern methods do not appear before Cataneo (A.D. 1546). Cataldi (A.D. 1613), the author of the *Trattato*, was one of the first writers to use similar methods in their entirety. In the fourth century A.D., Theon of Alexandria, the noted commentator of Ptolemy's *Almagest*, gave a method for approximate extraction of square roots of sexagesimal fractions, but it was approximate, algebraical and different from the Hindu method. In China, methods of extraction of square root (*khai fang*) and cube roots (*khai li fang*) with the help of counting boards appear in the *Chiu-chang Suan-shu* (latter half of the first century A.D.).[a]

Ratio, Proportion and Rule of Three

Problems of simple ratio and proportion were effectively handled by the ancient Indians by the Rule of Three, *trairāśika*, and the Inverse Rule

[a] Mikami, pp. 13–14; *see also* Needham, III, pp. 65–68.

of Three, *vyasta-trairāśika*. Problems involving compound proportions were dealt with the rules of five, seven, nine, etc., depending on the number of terms involved. The Rule of Three is given in the Bakhshālī Manuscript, by Āryabhaṭa, Brahmagupta and other writers of arithmetical works, whereas rules and cases of compound proportions are met with from Brahmagupta onwards.

In the Rule of Three, the problem is to find what *c* will produce when *a* produces *b*, *a* and *c* being of the same kind and *b* being different. Here, *a* is the argument called *pramāṇa* in the Hindu texts, *b* the fruit, *phala*, and *c* the requisition, *icchā*. Āryabhaṭa's rule is: 'In the rule of three, multiply the fruit by the requisition and divide by the argument. The result will be the fruit of the requisition.'[a] Bhāskara II states that the argument and requisition must be of like denomination whereas the fruit is of a different species. For Inverse Rule of Three, he further says, the operation is to be reversed.

For compound proportion, that is in the method of five, seven, nine and more, Bhāskara II directs as follows: 'Transpose the fruit and the divisors; divide the product of the larger set of terms by that of the less; the quotient is the result (sought).'[b] In such problems, there are two sets of terms, one set belonging to the argument and the other to the requisition. The fruit term in the argument set is to be transferred to the requisition side; likewise, the divisor term, if any, on the requisition side is to be transferred on the side of the argument. The remaining part of the rule is quite clear.

The Rule of Three was rated very high among the Indian mathematicians because, with the exception of squaring, square root, cubing and cube root, most of the calculations commonly required involve this rule. Soon after its appearance in the West, it began to be described as a golden rule. Robert Recorde (*c.* 1542), the most influential English mathematician of the sixteenth century, calls it 'the Rule of Proportions, which for its excellency is called the Golden Rule'. In explaining why it is commonly called the Golden Rule, Hodder, an English arithmetician of the seventeenth century, says, '. . . and indeed it might be so termed; for as Gold transcends all other Metals, so doth this Rule all others in Arithmetick'.[c] Transmission of the Rule of Three from India to Europe through Arab intermediaries is strongly suspected, for the name is found among the Arab and Latin writers. Pacioli (1494) calls it 'La regola del 3', Pellos (1492) the 'Regula de tres causas'; Chuquet (1484) 'La rigle de troys' and Rudolff (1526) 'Die Regel de Tri' whence its German abridgement 'Regeldetri'.

GEOMETRY

In the period we are considering geometry did make a progress from the point where it was left by the Vedic *śulbavids*, but it did not develop into the type of demonstrative and deductive geometry so favourite among

[a] *Ā. Gaṇita.*, 26. [b] *Lī.*, 79. [c] Smith (D. E.), II, pp. 486.

the Greeks. Analytical geometry, algebraic solutions of rational triangles, quadrilaterals, etc., continued to interest the Hindu mathematicians.

Āryabhaṭa, in introducing a few geometrical propositions, says that a circle is drawn by turning, the triangle and the quadrilateral are determined by *karṇa* (hypotenuse, diagonal), the horizontal is ascertained by water and the perpendicular by the plumb-line. The term *kṣetra-vyavahāra* used by Bhāskara II is interpreted by Gaṇeśa to mean determination of plane figures. Plane figures are fourfold, e.g. triangle, quadrangle, circle and bow. Bhāskara II gives an aphorism that it is not possible to have a rectilinear figure of which one side exceeds or equals the sum of the other sides.[a]

Triangle

In two rules of his *Gaṇitapāda*,[b] Āryabhaṭa indicates proportionality of sides in two similar triangles. These have applications in the gnomon and shadow problems. Āryabhaṭa gives the property of right-angled triangles as the square of the *bhuja* (perpendicular side) plus the square of the *koṭi* (side) being equal to square of the *karṇa* (hypotenuse); that is $x^2+y^2=z^2$. General solutions for such rational triangles are given by Brahmagupta, Mahāvīra, Bhāskara and other writers. Several rules of the *śulba-sūtras* also envisage solutions of rational triangles.

The solutions in the form m^2-n^2, $2mn$ and m^2+n^2 for the *bhuja*, *koṭi* and the hypotenuse are given by Brahmagupta, Mahāvīra and Bhāskara. Mahāvīra puts it as: 'The difference of the squares is the perpendicular, twice their product is the base and the sum of the squares gives the diagonal of a generated (*janya*) rectangle.' In another set of solution, where the side a is given, Bhāskara II directs this side to be multiplied by twice an assumed number n and divided by the square of that number less unity to get the perpendicular. To obtain the hypotenuse, the perpendicular so obtained is to be multiplied by the assumed number and the side is to be subtracted from the product. Thus the solutions are:

$$a, \frac{2an}{n^2-1} \quad \text{and} \quad \frac{2an^2}{n^2-1}-a \quad \text{or} \quad \frac{a(n^2+1)}{n^2-1}$$

The area of the triangle as the product of the perpendicular and half the base is uniformly given by all authors. Brahmagupta, Mahāvīra and Bhāskara II further express the area as

$$\sqrt{s(s-a)(s-b)(s-c)},$$

where $s=\frac{1}{2}(a+b+c)$.

Quadrilateral, Trapezium

Bhāskara II, in one of his aphorisms, states that, for the same set of sides of a quadrilateral, there are other diagonals, and so the area of the

[a] *Lī.*, 161.

[b] *Ā. Gaṇita.*, 15–16.

figure is manifold, for, in such a figure the opposite angles being made to approach, shorten their diagonal and the other pair going outwards lengthen theirs.[a] Mahāvīra defines five types of quadrilaterals: (1) *samacaturasra* (equilateral), (2) *dvidvisamacaturasra* (equi-dichastic), (3) *dvisamacaturasra* (equilateral), (4) *trisamacaturasra* (equitrilateral) and (5) *viṣamacaturasra* (inequilateral). For an equilateral tetragon (*tulyacaturbhuja*) of side a, if one diagonal d_1 be given, the other d_2 is given by

$$d_2 = \sqrt{4a^2-d_1^2}.$$

The area of such a tetragon is given by $\frac{1}{2}d_1d_2$. For trapeziums, the area is given by Āryabhaṭa and others as $\frac{1}{2}h(a+b)$, where h is the perpendicular and a and b the parallel sides.

Brahmagupta, Mahāvīra and Bhāskara also give the area of a quadrilateral in terms of the sides a, b, c and d and s (where $2s = a+b+c+d$) as

$$A = \sqrt{(s-a)(s-b)(s-c)(s-d)},$$

a result true only for cyclic quadrilaterals, but not for any quadrilateral. Brahmagupta states the above result as follows:

bhujayogārdhacatuṣṭaya bhujonaghātātpadaṃ sūkṣmam

That is, 'Put down half the sum of the sides four times, reduce (each) by the sides, multiply the results and take square root; the exact area (is obtained).' Brahmagupta did not limit the result to cyclic quadrilaterals only for which the formula holds good. This limitation was realized by Bhāskara II who stated that such a rule, though accurate for a triangle, was inexact for a quadrilateral. For such quadrilaterals, his diagonals were expressed in terms of the sides as follows:

$$p = \sqrt{\frac{(ac+bd)(ad+bc)}{ab+cd}}$$

$$q = \sqrt{\frac{(ac+bd)(ab+cd)}{ad+bc}}$$

It is again Brahmagupta who expressed the diagonals of quadrilaterals in the above manner. An English rendering of his rule runs as follows: 'The sides adjoining each of the two diagonals are multiplied and added and (the two sets of results) are divided by each other; the quotients are multiplied by the sum of the products of the opposite sides; the square roots (of the results) give the diagonals.'[b]

The above results were rediscovered by W. Snell in the seventeenth century in Europe. Ptolemy is generally credited with the formula

$$pq = ac+bd$$

which directly follows from the above result. But to Brahmagupta belongs the credit of obtaining expressions for the diagonals which easily lead to the above formula.

[a] *Lī.*, 170.

[b] *Br. Sp. Si.*, xii. 28.

The mathematicians of this period also studied the conditions for obtaining various types of rational quadrilaterals. Let us consider the question of constructing an isosceles trapezium whose sides, diagonals, altitudes and areas are all rational numbers.

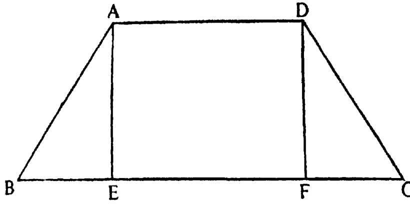


FIG. 3.14

Suppose p, q and r are suitably selected integers. A rational right triangle ABE (Fig. 3.14) is constructed such that

the diagonal $AB = p^2+q^2$
the side $BE = p^2-q^2$
the perpendicular
$AE = 2\,pq.$

According to the rule given by Brahmagupta,[a] the face AD and the base BC of the isosceles trapezium $ABCD$ are given by:

$$AD = \frac{1}{2}\left(\frac{4p^2q^2}{r} - r\right) - (p^2-q^2)$$

$$BC = \frac{1}{2}\left(\frac{4p^2q^2}{r} - r\right) + (p^2-q^2)$$

The area of the trapezium $= pq\left(\frac{4p^2q^2}{r} - r\right)$

It is clear that all the above elements are rational numbers. This is one of the many cases of rational and inscribed quadrilaterals discussed by the mathematicians of ancient and medieval India.

Circle, π

In the geometry of the circle, the most important element is the ratio of its circumference to its diameter, that is π. Various approximate values of π, we have already seen, had been in use in India from the time of the *śulba-sūtras* and early Jaina and Brāhmaṇa mathematicians. More accurate astronomical computations demanded an accurate value of π for which the older values such as 3, $\sqrt{10}$, 3·0883 became more and more insufficient. Brahmagupta still continued to use 3 as an approximate value good for practical purposes and $\sqrt{10}$ as the accurate one. But Āryabhaṭa in the fifth century had already given a value 3·1416 correct up to four decimal places in the following manner:

caturadhikaṃ śatamaṣṭaguṇaṃ dvāṣaṣṭistathā sahasrāṇām |
ayutadvayaviṣkambhasyāsanno vṛttapariṇāhaḥ || (*Gaṇitapāda*, 10)

[a] *Br. Sp. Si.*, xii. 36.

which means:

'Add four to one hundred, multiply by eight and then add sixty-two thousand; the result is approximately the circumference of a circle of diameter of twenty thousand.'

In other words,

$$\pi = \frac{\text{circumference}}{\text{diameter}} = \frac{8(100+4)+62{,}000}{20{,}000} = \frac{62{,}832}{20{,}000} = 3{\cdot}1416$$

Āryabhaṭa still called it an approximate (*āsanna*) value. This value was adopted by Lalla, mentioned by Bhaṭṭotpala in his commentary of Varāhamihira's *Bṛhatsaṃhitā* and finally by Bhāskara II in the reduced form $\frac{3927}{1250}$. Al-Khwārizmī, the celebrated Arab mathematician of the ninth century, reproduced Āryabhaṭa's value in his *Algebra*, almost in the same language, which, in Rosen's translation, runs as follows:

'The other method is used by the astronomers among them; it is this, that you multiply the diameter by sixty-two thousand eight hundred and thirty-two and then divide the product by twenty thousand; the quotient is the periphery.'

The value of π as $\frac{22}{7}$ is met with in Āryabhaṭa II's *Mahāsiddhānta*[a] and in Bhāskara II's *Līlāvatī*. This value along with the one reduced from Āryabhaṭa's is given by Bhāskara as follows:

'The diameter of the circle multiplied by three thousand nine hundred and twenty-seven and divided by twelve hundred and fifty gives the near circumference; alternatively, (the diameter) multiplied by twenty-two and divided by seven gives the gross circumference used in practice.'[b]

The Chinese value $\frac{355}{113}$ of π, given in the *Tsu Ch'ung-chih* (*c*. A.D. 370), occurs in India in a fifteenth-century collection of rituals, the *Tantrasamuccaya*. In medieval India, a renewed interest in working out still more accurate values of π is noticed among the mathematicians of south India, where traditional astronomy had also a new lease of life. In the *Karaṇapaddhati*, *Tantrasaṃgraha* and other works, the values of π are given in the form of series, of which the equivalent in decimal is 3·1415926535... Some of the series given in the *Karaṇapaddhati* are as follows:

$$(1)\ \pi = 4\left(1-\frac{1}{3}+\frac{1}{5}-\frac{1}{7}+\frac{1}{9}\cdots \pm \frac{p/2}{p^2+1}\right),$$

where p is the last odd divisor less unity.

$$(2)\ \pi = 2+4\left(\frac{1}{2^2-1}-\frac{1}{4^2-1}+\frac{1}{6^2-1}-\frac{1}{8^2-1}+\cdots\frac{1}{(p-1)^2+4}\right),$$

where p is the last even number squared.

[a] *MSi.*, xv. 92, 94, 95.

[b] *Lī.*, 201.

$$(3)\ \pi = 3+6\left(\frac{1}{1.3.3.5}+\frac{1}{3.5.7.9}+\frac{1}{5.7.11.13}+\ldots\right).$$

For the area of the circle, Āryabhaṭa gives $\frac{1}{2}cr$, where c is the circumference, Brahmagupta $3\left(\frac{d}{2}\right)^2$ for 'gross' and $\sqrt{10}\left(\frac{d}{2}\right)^2$ for 'neat' values and Bhāskara II $\frac{1}{4}dc$. For the area of a trapezium, Āryabhaṭa correctly gives the expression $\frac{1}{2}h(a+b)$. Mahāvīra's value for the area of an ellipse is $2ab+b^2$ as against the correct value of πab. For the volume of the sphere, Āryabhaṭa gives $\pi r^2 \times \sqrt{\pi r^2}$ or $\sqrt{\pi}.\pi r^3$ or $1{\cdot}47\pi r^3$. Bhāskara gives the area of a circle and that of the surface and the volume of a sphere correctly as πr^2, $4\pi r^2$ and $\frac{4}{3}\pi r^3$ respectively in one rule as follows:

> 'A quarter of the diameter multiplied by the circumference is the area of a circle. That (area of the circle) multiplied by four is the net covering the surface of the ball (that is the surface of the sphere). The surface of the sphere multiplied by the diameter and divided by six gives the exact volume of the sphere, its cubic content.'[a]

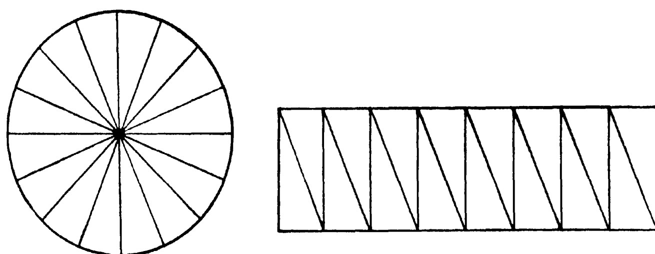


FIG. 3.15

Gaṇeśa gives simple proofs of the above areas and volume for circle and sphere. For any circle, it is first divided into two equal parts and each part into a very large number of equal triangular strips by drawing radii to the circumference. The semi-circles are then imagined to be stretched into a straight line opening at the triangular strips (Fig. 3.15). The two sets of triangular strips can then be made to fit into each other so as to form a rectangular strip equal to radius × half circumference or πr^2. Bhāskara II, in his *Golādhyāya*, gives a method of finding the surface of the sphere. From this the volume of the sphere is determined by imagining the sphere to be divided into as many pyramids as there are unit square areas on the surface, the height of each pyramid being equal to the radius. The volume of each pyramid is $\frac{1}{3}\times$ radius $\times$ unit square area, from which that of the sphere becomes equal to $\frac{1}{3}\times$ radius $\times$ surface of the sphere or $\frac{4}{3}\pi r^3$. Much

[a] *Lī.*, 203.

earlier Brahmagupta had given the volume of a cone or pyramid as one-third the volume of a cylinder or prism having the same base and height, that is $\frac{1}{3}\times$base area$\times$height—*kṣetraphalaṃ vedhaguṇasamakhātaphalaṃ hṛtaṃ tribhiḥ sūcyāḥ.*[a]

Another relation frequently given by the writers of this period is that when a diameter of a circle bisects a chord, the product of the two segments (*śaras*) of the diameter is equal to the square of the half-chord (Āryabhaṭa). That is

$$c^2 = ab.$$

Brahmagupta gives the rule in the form

$$2c = \sqrt{4a(d-a)},$$

where d = diameter.

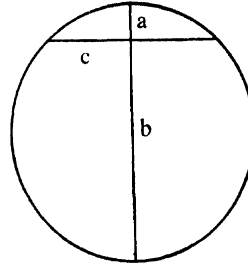


FIG. 3.16

ALGEBRA

Terminology

Algebra, or more correctly, the geometrical methods of solving algebraic problems, had their crude beginnings in the efforts of the altar-geometers of the Vedic times. As a distinct branch of mathematics, it appeared from about the time of Brahmagupta. This development was due largely to the perfection of the technique of indeterminate analysis and to a growing interest in such analysis which found ready applications in astronomical calculations. In fact, Brahmagupta used the terms *kuṭṭaka, kuṭṭaka-gaṇita* for algebra. The term *bīja-gaṇita* in the sense of calculation with unknown quantities (*bīja*) was hinted at by Brahmagupta's scholiast Pṛthūdakasvāmī, and was used by Bhāskara II. Various terms for the unknown quantity are met with in the Hindu mathematical literature, e.g. *yāvat-tāvat, yadṛcchā, vāñcchā, varṇa, kāmika, gulikā* and *avyakta.*

Equations, Classification, Symbols

For the equations the various technical terms used were *samakaraṇa, samī-karaṇa, sadṛśī-karaṇa,* etc. The *Sthānāṅga-sūtra* classifies them according to the powers of the unknown quantity into the following: the simple (*yāvat-tāvat*), the quadratic (*varga*), the cubic (*ghana*) and the biquadratic (*varga-varga*). According to Brahmagupta's classification, equations fall into the following groups:

(1) equations in one unknown (*eka-varṇa-samī-karaṇa*);
(2) equations in many unknowns (*aneka-varṇa-samī-karaṇa*);
(3) equations with products of unknowns (*bhavita*).

[a] *Br. Sp. Si.*, xii. 44.

This classification is determined by the number of different unknown quantities and not by the powers of such quantities. Accordingly, each class may include linear, quadratic, cubic or higher power equations.

For writing algebraic equations it is necessary to use some kind of symbols for the unknown quantities, symbols of operations, powers and roots. For unknown quantities we have noticed the practice of using a symbol for zero or vacant place in the Bakhshālī MS. The use of the letters of the alphabet is strongly indicated by the use of the word *varṇa* (letters of the alphabet). Various colour names, e.g. *kālaka* (black), *nīlaka* (blue), *pīta* (yellow), *lohita* (red), or abbreviations of the names of precious gems, e.g. *mā* (for *māṇikya*, ruby), *nī* (for *indra-nīla*, sapphire), *mu* (for *muktā-phala*, pearl), etc., served this purpose. For symbols of operations, *yu* (for *yuta*) was used for addition, + (possibly from the Brāhmī symbol for *k* in *kṣaya*) for subtraction, *gu* (from *guṇa*) for multiplication and *bha* (from *bhāga*) for division. As to powers and roots, *va* (from *varga*) directed squaring, *gha* (from *ghana*) cubing, *va-va* (from *varga-varga*) squaring the square, that is finding the fourth power, and *mū* (from *mūla*) finding the square root. The following examples from the Bakhshālī MS. illustrate some of the plans of writing equations:[a]

0	5	*yu*	*mū*	0	*sa*	0	7	±	*mū*	0
1	1			1		1	1			1

means $\sqrt{x+5} = s$

$\sqrt{x-7} = t$

0	2	1	3	3	12	4	*dṛśya* 300
1	1	1	1	1	1	1	

means $x+2x+3\times 3x+12\times 4x = 300$

Rule of False Position (*regula falsi*)

This primitive method of solving simple linear equations of the type $ax+b = 0$, by substituting guess values g_1, g_2, etc., was in extensive use among the Arab and European mathematicians in the Middle Ages. In India, its traces have been preserved in the *Sthānāṅga-sūtra* in the use of the term *yāvat-tāvat* and the Bakhshālī MS. Al-Khwārizmī, Qustā ibn Lūqā, Abu Kāmil and others used the rule called *ḥisab al-khataayn* in Arabic, which appeared as *el-cataym, elchataym*, etc., in medieval Latin treatises. Smith expressed the view that the rule as used in the Middle Ages had possibly come from India.

[a] Datta (1), pp. 28–29.

Quadratic Equations

The *śulba-sūtras* contain problems involving quadratic equations of the type $ax^2 = c$; $ax^2+bx = c$. The Bakhshālī MS. gives the solution of a problem in the form which reduces to:

$$x = \frac{\sqrt{B^2-4AC}-B}{2A}.$$

None of them gives any rule for solving such equations. Both Āryabhaṭa and Brahmagupta clearly indicate their knowledge of quadratic equations and their solutions. In connection with an interest problem, the *Āryabhaṭīya* contains the following solution:[a]

> *mūlaphalaṃ saphalaṃ kālamūlaguṇamardhamūlakṛtiyuktam* |
> *mūlaṃ mūlārdhonaṃ kālahṛtaṃ syāt svamūlaphalam* ||

which means:

> 'Multiply the sum of the interest on the principal and the interest on this interest by the time and by the principal. Add to this result the square of half the principal. Take the square root of this. Subtract half the principal and divide the remainder by the time. The result will be the interest on the principal.'

The result may be expressed in symbols as follows:

$$x = \frac{-p+\sqrt{p^2+4tpq}}{2t}$$

where p = principal; t = time; q = sum of interest on principal and interest on interest in time t; x = interest on principal in unit time.

A similar quadratic solution arising out of an interest problem is given by Brahmagupta. Such quadratic problems also arise in finding the number of terms (n) in an A.P. Both Āryabhaṭa and Brahmagupta give the results correctly, which, as Rodet (in the case of *Āryabhaṭīya*) pointed out long ago, indicate knowledge of the solutions of quadratic equation of form $ax^2+bx+c = 0$.

The method of transforming into a whole square the left-hand side of the quadratic equation $ax^2+bx = c$ by multiplying both sides by $4a$, adding b^2 and taking the square root is given by Śrīdhara in his algebra which is lost, but preserved in the quotations of Bhāskara II, Jñānarāja and Sūryadāsa.

The rule is:

> *caturāhatavargasamai rūpaiḥ pakṣadvayaṃ guṇayet* |
> *avyaktavargarūpairyuktau pakṣau tato mūlam* ||

---

[a] *Ā. Gaṇita.*, 25; the Eng. trans. given of the verse is by Clark.

That is:

> 'Two sides are to be multiplied by four times the coefficient of the square of the unknown; the square of the coefficient of the unknown is to be added to both sides; then the square root (is to be taken).'

Indeterminate Equations of the First Degree

This branch of algebra, as we have seen, interested the Indian mathematicians and astronomers from the time of the *śulba-sūtras*. Detailed rules of solution are given in the works of Āryabhaṭa I, Bhāskara I, Brahmagupta, Mahāvīra, Āryabhaṭa II, Bhāskara II and later authors and commentators. Indeterminate analysis had an immediate application in astronomy in the determination of the cycle (*yuga*) of planets from the elapsed cycles of several other given planets.

Āryabhaṭa and Brahmagupta gave rules for finding the value of N from

$$N = ax+r_1 = by+r_2$$

which is the same as finding the solution of the indeterminate equation

$$by = ax\pm(r_1-r_2) = ax\pm c,$$

where a and b are called the divisors (*bhāgahāra*), r_1 and r_2 the corresponding remainders (*agra*) and c the difference of remainders (*agrāntara*). Mahāvīra, Āryabhaṭa II and Bhāskara II chose the form

$$y = \frac{ax\pm c}{b},$$

where a was called the dividend (*bhājya*), b the divisor (*hāra*), c the interpolator (*kṣepa*), x the multiplier (*guṇa*) and y the quotient (*phala*). All the authors have clearly stated that the equation admits of solution only when a and b are prime to each other. Methods of solving simultaneous indeterminate equations called conjunct pulverizer (*saṃśliṣṭa kuṭṭaka*) of the form

$$by_1 = a_1x\pm c_1$$

$$by_2 = a_2x\pm c_2$$

$$by_3 = a_3x\pm c_3$$

are given by Āryabhaṭa II and Bhāskara II.

Indeterminate Equations of the Second Degree

The great merit of solving in rational integers indeterminate equations of the second degree having the general form

$$Nx^2\pm c = y^2$$

$$Nx^2\pm 1 = y^2$$

has been traced to the genius of Brahmagupta. Further refinements, clarifications and extensions were due to subsequent Indian mathematicians such as Śrīpati, Bhāskara II, Nārāyaṇa and others including several commentators who rendered no small service to this branch of algebra.

The Hindu mathematicians call this type of equations *varga-prakṛti* (square-nature), in which N is termed *guṇaka prakṛti*, x *kaniṣṭha pada*, *hrasva-mūla* or *ādya-mūla*, y *jyeṣṭha-pada*, *jyeṣṭha-mūla* or *anya-mūla*, c *kṣepa*, *prakṣepa* or *prakṣepaka*. Brahmagupta's formulation of the equation is indicated in the first line of his well-known lemma.

In clearer terms Bhāskara II defines the equation as follows:[a]

> *iṣṭaṃ hrasvaṃ tasya vargaḥ prakṛtyā kṣuṇṇo yukto varjito vā sa yena |*
> *mūlaṃ dadyāt kṣepakaṃ taṃ dhanarṇaṃ mūlaṃ tacca jyeṣṭhamūlaṃ vadanti ||*

which means:

> 'The square of the optional lesser number (*iṣṭa hrasva*) multiplied by the *prakṛti* and increased or decreased by the positive or negative interpolator (*kṣepaka*) gives a square root called the greater root (*jyeṣṭha-mūla*).'

That is

$$Nx^2 \pm c = y^2.$$

The method adopted by Brahmagupta and other early mathematicians was to find a first set of integral values a and b of x and y and form the auxiliary equation

$$Na^2 \pm 1 = b^2.$$

From these an unlimited number of integral solutions can be readily obtained by the lemma discovered by Brahmagupta and applied by later mathematicians. The Sanskrit term for the lemma is *bhāvanā*. Brahmagupta gave the lemma as follows:

> *mūlaṃ dvidheṣṭavargādguṇakaguṇādiṣṭayutavihīnācca |*
> *ādyavadhoguṇakaguṇāḥ sahāntyaghātena kṛtamantyam ||*
> *vajravadhaikyaṃ prathamaṃ prakṣepaḥ kṣepavadhatulya |*
> *prakṣepaśodhakahṛte mūle prakṣepake rūpe ||*

The above may be translated as follows:

> 'An optional number added to or subtracted from the product of the square of a number and an optional multiplier yields a square root. (Carry out the operation) twice (and set one below the other). The product of the two first or lesser roots multiplied by the multiplier and then added to the product of the two last or greater roots gives the last or greater root. The sum of the cross-products

[a] *BBī. Vargaprakṛti*, 1.

of the first and the last roots gives the first root. Similarly, the interpolator will be the product of the (two) interpolators. For (finding the roots of the equation with) unity as interpolator, divide the roots by the square of the interpolator.'

Bhāskara II expresses the lemma as follows:

'The lesser root, the greater root and the interpolator being set down, other (similar) quantities are to be set down below in order. From them several roots may be obtained by the method of *bhāvanā*. Now *bhāvanā* is being explained. The sum of the cross-multiplication of the two greater and lesser roots gives the lesser root. The sum of the product of the two lesser roots multiplied by the multiplier and the product of the two greater roots gives the greater root. The product of the interpolators gives the interpolator.'

In the next stanza, Bhāskara states that the rule holds good if, instead of the sum, the difference be taken. In algebraic symbols, if a_1, b_1, c_1 and a_2, b_2, c_2 be two sets of values for x, y and the interpolator of an equation of square nature whose *prakṛti* or multiplier is N, these are to be written down as follows:

$$Na_1^2+c_1 = b_1^2,$$
$$Na_2^2+c_2 = b_2^2.$$

Then, $x = a_1b_2 \pm a_2b_1$ and $y = b_1b_2+Na_1a_2$ will satisfy the equation:[a]

$$Nx^2+c_1c_2 = y^2.$$

By the method of *bhāvanā* or composition, one can obtain an infinite number of solutions as stated in the rule itself. In Europe, Fermat (*c.* A.D. 1640) was once believed to be the first to have stated that an indeterminate equation of the second degree of the type discussed above has an unlimited number of integral solutions. The equation with interpolator was mistakenly called Pellian equation after John Pell (1668), the younger contemporary of Fermat. In India, such equations and full methods of solving them appeared more than a thousand years before they did in Europe.

Cakravāla or the Cyclic Method

We have stated that to solve the indeterminate equation of the second degree of the type discussed it is necessary to form an auxiliary equation in positive integers of a, b and c. Brahmagupta did it by trial and error method for values of $c = \pm 1$, ± 2, ± 4. Bhāskara II proposed to solve the problem by a method he termed *cakravāla* and stated it as follows:

hrasvajyeṣṭhapadakṣepān bhājyaprakṣepabhājakān |
kṛtvā kalpyo guṇastatra tathā prakṛtitaścyute ||
guṇavarge prakṛtyone'thavā'lpaṃ śeṣakaṃ yathā |
tattu kṣepahṛtaṃ kṣepo vyastaḥ prakṛtitaścyute ||

[a] Datta and Singh, II, 146–49.

guṇalabdhiḥ padaṃ hrasvaṃ tato jyeṣṭhamato'sakṛt |
tyaktvā pūrvapadakṣepāṅścakravālamidaṃ jaguḥ ||

The above may be translated as follows:

'The lesser root, the greater root and the interpolator are to be regarded as the dividend, the additive quantity and the divisor respectively (as in the *kuṭṭaka*). The multiplier (of the *kuṭṭaka*) is to be so chosen that its square less the *prakṛti* or vice versa is the least. This (least) quantity divided by the interpolator is the interpolator (of the new equation); its sign will be reversed if the square of the multiplier be subtracted from the *prakṛti*. The quotient (of the *kuṭṭaka*) corresponding to the multiplier is the lesser root. From this the greater root (is obtained). Putting aside the former roots and the interpolator the same process is to be repeated (to obtain similar sets of values and so on). This is called the *cakravāla*.'

The method seeks to derive from the equation

$$Na^2+c = b^2$$

the following equation

$$N\left(\frac{am+b}{c}\right)^2+\frac{m^2-N}{c} = \left(\frac{bm+Na}{c}\right)^2.$$

Here m is the multiplier such that m^2-N is the smallest. This multiplier is determined by the method of pulverizer (*kuṭṭaka*), of which the quotient $\frac{am+b}{c}$ is the lesser root. Note how the pulverizer is formed by taking the lesser root a as the dividend, the greater root b as the additive quantity and the interpolator c as the divisor, as stated in the first line of the rule.[a]

Surds

Operations with quantities like $\sqrt{2}$, $\sqrt{3}$, $\sqrt{18}$, etc. were already well known at the time of compilation of the *śulba-sūtras*. We have seen some of the technical terms then used as also geometrical methods of determining the approximate values of such quantities. In the second or the third century A.D., Heron of Alexandria determined values of surds with the help of the following formula:

$$\sqrt{N} = \sqrt{a^2+r} = a+\frac{r}{2a}.$$

In the centuries before the Christian era, the Jainas appear to use the above relation in obtaining the value of $\sqrt{10}$, their approximate value of π. The same formula with higher terms is given in the Bakhshālī MS. as follows:

$$\sqrt{N} = \sqrt{a^2+r} = a+\frac{r}{2a}-\frac{\left(\frac{r}{2a}\right)^2}{2\left(a+\frac{r}{2a}\right)}.$$

[a] Sengupta (1), pp. 73–80.

In the form of rule:[a]

> 'In the case of a non-square (number), subtract the nearest square number; divide the remainder by twice (the root of that number). Half the square of that (that is the fraction just obtained) is divided by the sum of the root and the fraction (*saṃśliṣṭa*) and subtract; (this will be the approximate value of the root) less the square (of the term).'

The following are some of the examples cited for the extraction of the root by the above rule:

$$\sqrt{41} = 6+\frac{5}{12}-\frac{\left(\frac{5}{12}\right)^2}{2\left(6+\frac{5}{12}\right)},$$

$$\sqrt{105} = 10+\frac{1}{4}-\frac{\left(\frac{1}{4}\right)^2}{2\left(10+\frac{1}{4}\right)}.$$

According to another ingeneous method due to Nārāyaṇa Paṇḍita, a second degree indeterminate equation (square nature) was first formed and solved; the ratio of the higher to the lesser root gave the approximate root sought. Let N be the number whose square root is sought. The square nature with this number will be

$$Nx^2+1 = y^2.$$

If a and b be the lesser and the higher root by solution of the above,

$$\sqrt{N} = \frac{b}{a} \text{ approximately.}$$

In Nārāyaṇa's formulation,[b]

> 'Find the roots (of a square nature) with the number whose square root is desired (as the multiplier) and unity as the additive and divide the greater root by the lesser; the result will be the approximate value of the square root.'

Progressive Series

Problems connected with progressive series, particularly the A.P. and the G.P., had interested the Vedic Hindus. Although a number of such series are mentioned in the *Saṃhitās* and their sums given correctly in some cases, there is no indication of any general rule or rules by which to obtain the sum. These rules we find neatly versified in the works of Āryabhaṭa, Brahmagupta and others following them. This branch of study came to be called *Śreḍhī-vyavahāra*. Some of the technical terms used in connection with the series are: the first term, *a—ādi, mukha, vadana*; common

[a] Datta (1), pp. 11 ff.

[b] Datta (3), pp. 187–94.

difference, *d—caya, pracaya, uttara*; middle term, *m—madhya*; last term, *l—antya*; number of terms, *n—pada, gaccha*; sum of the series, *s—średhī-phala, gaṇita, sarvadhana, saṃkalita.*

For the summation of the A.P.

$$a, a+d, a+2d, \ldots \text{ up to } n \text{ terms,}$$

all the authors mentioned above give the last and the middle terms and the sum as follows:

$$l = a+(n-1)d,$$

$$m = \tfrac{1}{2}[2a+(n-1)d],$$

$$s = nm = \frac{n}{2}[2a+(n-1)d] \text{ or } \frac{n}{2}(a+l).$$

If the number of terms extend from the $(p+1)$th to the $(p+n)$th term in an A.P. of which the first term is a, Āryabhaṭa gives the sum as

$$s = n\left[a+\left(\frac{n-1}{2}+p\right)d\right],$$

where the entire expression within the bracket stands for the middle term.

From the above formula, n can also be calculated if s, a and d are known. The formulas given for this purpose are:

$$\text{(Āryabhaṭa):}\quad n = \frac{1}{2}\left[\frac{\sqrt{8sd+(2a-d)^2}-2a}{d}+1\right],$$

$$\text{(Bhāskara II):}\quad n = \frac{1}{d}\left[\sqrt{2sd+\left(a-\frac{d}{2}\right)^2}-\left(a-\frac{d}{2}\right)\right].$$

The summation of natural numbers, 1, 2, 3, ..., formation of triangular numbers of different orders and their summation, the summation of the squares and higher powers of the natural numbers were also investigated. A series of natural numbers is called by Āryabhaṭa *upaciti* and by Brahmagupta *ekottaramekādya.* Summation of triangular numbers of higher and higher orders is called by Nārāyaṇa *vārasaṃkalita.* Thus

$$\text{The first } \textit{vārasaṃkalita} = 1+2+3+\ldots n \text{ terms} = \frac{n(n+1)}{1.2}$$

$$\text{The second } \textit{vārasaṃkalita} = \frac{1.2}{2}+\frac{2.3}{2}+\frac{3.4}{2}\ldots\frac{n(n+1)}{2} = \frac{n(n+1)(n+2)}{1.2.3}$$

Several Hindu mathematicians up to Bhāskara II have given the summation of both the natural and the triangular numbers, as stated above. In the fourteenth century Nārāyaṇa extended the process to any higher order triangular numbers and gave a general formula for the summation up to the rth order or the rth *vārasaṃkalita* as follows:

$$\frac{n(n+1)(n+2)\ldots(n+r)}{\underline{|r+1}}$$

To Nārāyaṇa also belongs the credit of applying the above general formula to determining the rth summation of an A.P. of which the first term is a and the common difference d. The rth summation of such an A.P. up to n terms is given by

$$a\,.\,{}^{n-1}s_r\,.\,\frac{r+1}{n-1}+d\,.\,{}^{n-1}s_r$$

where ${}^{n-1}s_r$ represents the rth summation of $n-1$ natural numbers starting with unity.[a]

Brahmagupta and Bhāskara II have given the summation of the squares and the cubes of the natural numbers as follows:

$$1^2+2^2+3^2+\ldots n^2=\frac{n(n+1)}{2}\cdot\frac{(2n+1)}{3}$$

$$1^3+2^3+3^3+\ldots n^3=\left[\frac{n(n+1)}{2}\right]^2$$

As to geometrical progressions, having the first term a, a common multiplier r and number of terms n, Bhāskara II, in his *Līlāvatī* gives the modern rule and several examples. The sum is given by

$$s=\frac{a(r^n-1)}{r-1}.$$

The operations to obtain r^n in the formula are rather expressed in an involved manner, which is explained in Gaṇeśa's commentary.

In the fifteenth century, Nīlakaṇṭha and some of his contemporaries and followers successfully handled the summation of infinite series having a common divisor. To Nīlakaṇṭha was also due the geometrical derivation of some of the A.P. formulae discussed above.

TRIGONOMETRY

Definition of Trigonometrical Functions

Instead of dealing directly with the trigonometrical ratios, the ancient Hindus dealt with the lengths pertaining to the various elements of an arc of a circle of given radius. Their trigonometrical terminology will be better understood by referring to Fig. 3.17.

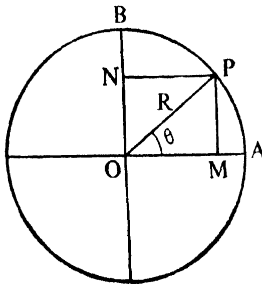


FIG. 3.17

For the arc AP called *dhanu*, bow of the circle with centre O, PM, the half-chord, is called the *jyā* or *ardha-jyā* or *jīva*, PN or OM the *koṭi-jyā* (also called *kojyā*) or the *jyā* of the arc complimentary to AP and MA, the difference between the radius and the *koṭi-jyā*, is called the *utkrama* (reversed)-*jyā*. Expressed in terms of sines and cosines as per modern definition,

[a] Saraswathi, pp. 322–23.

$$jy\bar{a}\ AP = PM = R\sin\theta$$
$$ko\d{t}i\text{-}jy\bar{a}\ AP = OM = R\cos\theta$$
$$utkrama\text{-}jy\bar{a}\ AP = MA = R\ \text{versin}\ \theta = R - R\cos\theta$$

A Few Trigonometrical Relations

In Varāhamihira's summary of the *Puliśa-siddhānta*, the values of $(R\sin 30)^2$, $(R\sin 45)^2$ and $(R\sin 60)^2$ are given as $R^2/4$, $R^2/2$ and $3R^2/4$ respectively, from which those of sin 30, sin 45 and sin 60 follow correctly. Some of the trigonometrical relations given in the early medieval astronomical texts are shown below:

(Āryabhaṭa I, *Sūrya-siddhānta*): $\sin(n+1)\alpha - \sin n\alpha = \sin n\alpha - \sin(n-1)\alpha - \dfrac{\sin n\alpha}{225}$

(Varāhamihira, Lalla): $\cos\theta = \sin\left(\frac{\pi}{2} - \theta\right)$

(Lalla, Brahmagupta): $\sqrt{1-\sin^2\theta} = \cos\theta$ or $\sin\left(\frac{\pi}{2}-\theta\right)$

$$\sqrt{1-\sin^2\left(\frac{\pi}{2}-\theta\right)} = \sin\theta$$

(Varāhamihira): $\sin^2\theta + \cos^2\theta = 1$

$$\sin^2\theta = \tfrac{1}{4}(\sin^2 2\theta + \text{versin}^2\, 2\theta)$$
$$= \tfrac{1}{2}(1-\cos 2\theta)$$

(Āryabhaṭa II): $\sin\left(\frac{\pi}{4} \pm \frac{\theta}{2}\right) = \sqrt{\dfrac{1 \pm \sin\theta}{2}}$

(Bhāskara II): $\sin(A \pm B) = \sin A\cos B \pm \cos A\sin B$

Sine Table

The various relations connecting the sine of any arc with their multiples and submultiples were given with a view to constructing or calculating sine tables for different arcs generally lying between 0 and 90°. The Hindu planetary theories, as we have seen in the section on astronomy, required such tables for computations of true planetary positions. The general formula shown against the name of Āryabhaṭa and the *Sūrya-siddhānta* was used for computing the tables of *jyā* or half-chords in a quadrant divided into 24 equal parts so that the smallest arc equals 3° 45′ or 225′. Since the Hindu sines are not the ratios of the corresponding half-chords and the radius, but represent the half-chords themselves, their values obviously depend upon the length of the radius chosen. The values of the radius adopted by Varāhamihira, Āryabhaṭa and Brahmagupta are 120′, 3438′ and 3270′ respectively; other writers have used such values as 150′, 3415′ and 1000′. The values of 24 sines as given in the *Pañcasiddhāntikā* and the *Āryabhaṭīya* are given in Table 3.4. From the half-chords given in the

texts, the sines of the angles are computed, which may be compared with the modern values given in the last column. The accuracy of the Hindu half-chord tables is quite obvious.

TABLE 3.4

Hindu half-chord (R sin θ) values of 24 angles in a quadrant

Angles	*Pañcasiddhāntikā*		*Āryabhaṭīya*		Modern value sin θ
	120′ sin θ	sin θ (computed)	3438′ sin θ	sin θ (computed)	
3° 45′	7′ 51″	0·06542	225′	0·06545	0·0654
7° 30′	15′ 40″	0·1305	449	0·1306	0·1305
11° 15′	23′ 25″	0·1951	671	0·1952	0·1951
15°	31′ 4″	0·2589	890	0·2589	0·2588
18° 45′	38′ 34″	0·3214	1105	0·3215	0·3214
22° 30′	45′ 56″	0·3827	1315	0·3824	0·3827
26° 15′	53′ 5″	0·4424	1520	0·4421	0·4423
30°	60′	0·5000	1719	0·5000	0·5000
33° 45′	66′ 40″	0·5278	1910	0·5555	0·5555
37° 30′	73′ 3″	0·6088	2093	0·6087	0·6088
41° 15′	79′ 7″	0·6594	2267	0·6595	0·6594
45°	84′ 51″	0·7071	2431	0·7071	0·7071
48° 45′	90′ 13″	0·7519	2585	0·7519	0·7519
52° 30′	95′ 13″	0·7934	2728	0·7936	0·7934
56° 15′	99′ 46″	0·8314	2859	0·8316	0·8315
60°	103′ 56″	0·8662	2978	0·8664	0·8660
63° 45′	107′ 38″	0·8971	3084	0·8973	0·8969
67° 30′	110′ 53″	0·9241	3177	0·9243	0·9239
71° 15′	113′ 38″	0·9469	3256	0·9471	0·9469
75°	115′ 56″	0·9663	3321	0·9658	0·9659
78° 45′	117′ 43″	0·9811	3372	0·9819	0·9808
82° 30′	119′	0·9917	3409	0·9915	0·9914
86° 15′	119′ 45″	0·9979	3431	0·9979	0·9979
90°	120′ 1″	1·0000	3438	1·0000	1·0000

Bhāskara I, Brahmagupta, Bhāskara II, Nārāyaṇa and others have given a formula, in different forms, for the calculation of the half-chord directly from the given arc, i.e. the angle. Expressed in modern terms, the formula is

$$R \sin \theta = \frac{4R\,\theta(180-\theta)}{40500-\theta(180-\theta)},$$

where R is the radius, θ any angle. Bhāskara I's rule is as follows:[a]

> 'The given arc (θ) in degrees is to be subtracted from the degrees of the half-circle (180°) and the remainder multiplied by the arc. The result is to be set down at two places. This result (at one place) is to be subtracted from 40500. Divide by one-fourth of this remainder the result (set down at another place) and multiply by the maximum value of the sine (that is radius). Thus is obtained the direct or the reversed sine of an arc and its complement approximately.'

Trigonometrical Series

We have noticed the development of an interest in series and their summation in higher and higher orders, the *vārasaṃkalita*. The process was applied to the arc of a circle to obtain expressions of infinite series for π, and trigonometrical functions $\sin\theta$, $\cos\theta$ and $\tan\theta$. In 1835, C. M. Whish first drew the attention of modern scholars to the existence of some of these series in the medieval astronomical-mathematical works *Karaṇapaddhati*, *Tantrasaṃgraha*, *Yuktibhāṣā* and *Sadratnamālā*. The series and their rationales have been recently studied more closely. The originality exhibited by these Hindu mathematicians and astronomers in handling along traditional lines series which occupied much later the attention of mathematicians like Roberval (A.D. 1634), Gregory (A.D. 1671) and Euler (A.D. 1739) is a clear indication that, at least in mathematics, the decline was not complete after Bhāskara II. The *Karaṇapaddhati*, now believed to be written by one Putumana Somayājin in the fifteenth century A.D., gives rules from which the following series can be derived:

$$\frac{\pi}{4} = 1-\tfrac{1}{3}+\tfrac{1}{5}-\tfrac{1}{7}+\tfrac{1}{9}-\dots$$

$$\sin\theta = \theta-\frac{\theta^3}{\underline{|3}}+\frac{\theta^5}{\underline{|5}}-\dots$$

$$\cos\theta = 1-\frac{\theta^2}{\underline{|2}}+\frac{\theta^4}{\underline{|4}}-\dots$$

$$\theta = \tan\theta-\tfrac{1}{3}\tan^3\theta+\tfrac{1}{5}\tan^5\theta-\dots$$

The series are more neatly described by Nīlakaṇṭha (*c.* A.D. 1500) in his *Tantrasaṃgraha*, while their demonstrations are given in the *Yuktibhāṣā* (*c.* A.D. 1639), a commentary in a highly Sanskritized form of Malayalam of the *Tantrasaṃgraha*.[b] The *Sadratnamālā* where these series are discussed is a nineteenth-century work.

Spherical Trigonometry

The representation of the celestial bodies and the various astronomical elements with the help of great and small circles in the celestial sphere

[a] *MBh.*, vii. 17–19.

[b] Marar and Rajagopal, pp. 65–82; Rajagopal, pp. 201–9.

necessitated handling of spherical triangles and their solutions. Although there is no exclusive work dealing with the properties of spherical triangles and the relations of their various elements, their properties and relations have been correctly applied in connection with several astronomical problems. This itself is a good evidence of the early appreciation by the Hindus of this branch of mathematics and its effective use in their favourite pursuit of astronomy. The following principal formulae for solving spherical triangles readily emerge from a series of astronomical rules scattered in the texts:

(i) $\cos a = \cos b \cos c + \sin b \sin c \cos A$

(ii) $\cos A \sin c = \cos a \cos b - \sin a \cos b \cos C$

(iii) $\dfrac{\sin a}{\sin A} = \dfrac{\sin b}{\sin B} = \dfrac{\sin c}{\sin C}$

where A, B and C are the angles of a spherical triangle, of which the opposite sides are a, b and c respectively. Since the Hindus did not deal with angles, but with lengths, their results were obtained with reference to suitable plane right-angled triangles in which the properties of similar triangles were frequently pressed into service. As an illustration, the problem of finding the rising times of the different signs of the ecliptic on the equator above the horizon may be considered. This reduces to finding the relationship between the longitude λ (polar longitude in Hindu astronomy), the obliquity ϵ and the declination δ of a planetary body on the ecliptic. The rule given by Āryabhaṭa and others may be represented as follows:

$$R \sin \delta = \frac{R \sin \lambda \,.\, R \sin \epsilon}{R}$$

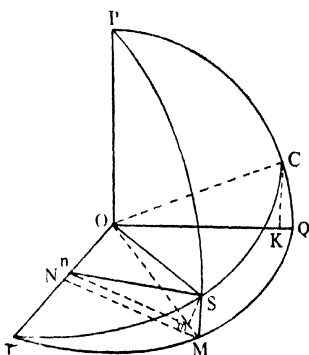


FIG. 3.18

In Fig. 3.18, ΥQ and ΥC are portions of the equator and the ecliptic, Υ the first point of Aries, ϵ the obliquity, S the position of the planet, and CK, Sm and Sn are normals to OQ, OM and $O\Upsilon$ respectively. Then, from the properties of similar triangles, COK and Snm,

$$\frac{Sm}{Sn} = \frac{CK}{OC}.$$

Now, $Sm = R \sin \delta$; $Sn = R \sin \lambda$; $CK = R \sin \epsilon$; $OC = R$.

Whence,

$$R \sin \delta = \frac{R \sin \lambda \,.\, R \sin \epsilon}{R}$$

or $\quad \sin \delta = \sin \lambda \sin \epsilon$,

a relationship which follows directly from the spherical triangle ΥSM by the application of relation (iii). Transformation of polar coordinates

into celestial longitudes and latitudes, relations between hour angles, azimuth and zenith distance and several others offer further examples of the application of spherical trigonometry to astronomical matters and in all cases the rules are given correctly in the Hindu astronomical texts.

CALCULUS

We have seen that the usual Hindu method in finding the area of a circle or the volume of a sphere consisted in dividing the area or the volume into a large number of small elements and then taking their sum. Bhāskara II, in particular, had recourse to this method as we have it from the exposition of his scholiast Gaṇeśa. In the case of the sphere, the entire volume used to be divided into a large number of pyramids of the same height equal to the radius of the sphere. The apex of each pyramid coincides with the centre, and the base lies on the surface. The base of each pyramid was taken to be a unit of the scale by which the area of the surface of the sphere was reckoned. The volumes of these pyramids were then summed up to obtain the volume of the sphere. Rudiments of integration are clearly noticeable in such methods.

Ideas of differentials, that is infinitesimal increase of a variable quantity due to infinitesimal increase in another quantity, are implicit in Bhāskara II's treatment of the instantaneous motions of planets. In his *Siddhānta-śiromaṇi*, he defines two kinds of planetary velocities, the gross or rough velocity (*sthūlā gati*) and velocity at an instant of time (*sūkṣmā* or *tātkālikī gati*). In the former, change of longitude over a long interval of time is considered and the gross velocity is found by dividing the change in longitude by the time interval. To find the *tātkālikī gati*, it is necessary to find an infinitesimal change in longitude, $d\lambda$, corresponding to an infinitesimal time interval, dt.

That Bhāskara II also carried out such differentiation is clearly indicated in his correct formulation of the expression for the *tātkālikī gati*. His rule runs as follows:[a]

> 'To find the instantaneous velocity (in longitude) of the planet, the *koṭiphala* is to be multiplied by the time rate of change of anomaly and divided by the radius, and the quotient (thus obtained) is to be added to or subtracted from the velocity of the mean planet according as its position is in the six signs from the beginning of Cancer or of Capricorn.'

The above rule can be expressed in modern mathematical notations as follows:

$$\frac{d\lambda}{dt} = \frac{d\bar{\lambda}}{dt} \pm \frac{1}{R} \cdot (r \cos \alpha) \cdot \frac{d\alpha}{dt}$$

where λ = true longitude, $\bar{\lambda}$ = mean longitude, α = anomaly, r = eccentricity or radius of the epicycle, $r \cos \alpha$ = *koṭiphala* and R = radius of the deferent circle.

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[a] *Si. Śi. Grahagaṇita*, 37.

According to the Hindu planetary theory, the equation of the centre is given by (*see* section on 'Astronomy', page 58)

$$\sin \mu = \pm \frac{r \sin \alpha}{R}$$

or $$\mu = \pm \frac{r \sin \alpha}{R}, \quad \text{since } \mu \text{ is small}$$

or $$\lambda = \bar{\lambda} \pm \frac{r \sin \alpha}{R}, \quad \text{since } \mu = \lambda - \bar{\lambda}$$

The above relation, on differentiation, leads to Bhāskara II's expression for $\frac{d\lambda}{dt}$. This also demonstrates Bhāskara's acquaintance with the result of differentiation of a sine function, e.g.

$$d(\sin \theta) = \cos . d\theta$$

STUDY OF ARABIC AND PERSIAN MATHEMATICS IN INDIA

The various Muhammadan houses and dynasties that ruled over extensive tracts of India in the medieval times not unoften patronized science and learning among their subjects. The contents of science and learning, it is needless to say, were what their Arabic and Persian masters of West and Central Asia had written about. Moreover, for a long time after the consolidation of Muhammadan rule in India, such Arabic and Persian science and learning remained confined to Muslim circles of learners and scholars, and it was not until quite late that such learning began to cross-fertilize the traditional sciences which the Hindus continued to cultivate among themselves. This is not to suggest that one group did not show any interest in the science and literature of the other. But the instances of an al-Bīrūnī zealously exploring Hindu works of science and literature, comparing and contrasting them with those of the system he represented, or of a Jagannātha mastering Arabic and Persian and assidously translating difficult astronomical and mathematical texts into Sanskrit were rare. For the most part the Hindus remained content with the works and commentaries of their learned traditional authors and the Muhammadans hardly felt the need of mastering the language and the sciences of the former.

As to promotion and patronage of learning, Sultan Mahmūd of the House of Ghazna did much to develop Muhammadan learning through the establishment of 'a university supplied with a vast collection of curious books in various languages. It contained also a museum of natural curiosities'.[a] Qutb-ud-dīn, of the 'Slave' Dynasty, himself proficient in Arabic, Persian and sciences, established several mosques which, like Christian churches of Medieval Europe, acted as centres of religion

[a] Briggs, I, p. 61.

and secular learning. Of the Tughluq kings, Ghiyāsuddīn built many public buildings for educational purposes, and provided for stipends to learned men; Muhammad was skilled in logic, medicine, astronomy and mathematics and Greek philosophy; Fīrūz established at Fīrūzābād a Mādrasah after his name, which, in the beauty of its architecture and scholarly reputation, surpassed all other Indian Mādrasahs of the time.[a] Fīrūz also showed considerable interest in Sanskrit technical literature and caused a few of them to be translated into Persian. Hindu astronomers also received encouragement in his court. Sultan Sikandar Lodī's reign is important in the literary and scientific history of India in the fact that during his time the Hindus seriously took to the study of Persian in which, as Blochmann observes, they soon attained a great proficiency and even caught up with the Muhammadans in literary excellences.

In the south, Fīrūz Shāh of the Bahamani Kingdom was a great scholar and patron of science and learning. He was fond of geometry and botany, among the scientific subjects, used to invite to his court learned men from abroad, and caused an astronomical observatory to be built (A.D. 1407) on the summit of a pass near Daulatābād.

With the establishment of the Mughal power in India, the Samarqand school of mathematicians and astronomers began to play a prominent part in the study of mathematics and astronomy among the Muhammadans in India. This is clearly mentioned by Bābur himself in his *Memoirs*. Humāyūn had a great liking for astronomy and geography and caused terrestrial and celestial globes to be constructed for the purpose. The enlightened rule of Akbar was also marked by considerable progress in secular learning in which the sciences were not neglected. It was during his reign that *Līlāvatī* was translated into Persian. In the educational system introduced in his time the study of mathematics received due emphasis among the sciences which used to be taught in the following order: morality, arithmetic, accounts, agriculture, geometry, astronomy, art of government, physics, natural philosophy and mathematics. The library of Faizī which, after his death, was transferred to the King's library, contained 4,600 volumes covering different disciplines such as medicine, astrology, astronomy, geometry, philosophy, philology, theology, poetry and music.

ARABIC AND PERSIAN MATHEMATICAL WORKS OF NON-INDIAN ORIGIN USED IN INDIA IN MEDIEVAL TIMES

It is pertinent to ask what authorities and which mathematical works in Arabic and Persian used to be taught and studied in medieval India. In the present state of our knowledge, a satisfactory answer cannot be given to this question, but a good idea may be obtained from the availability of manuscripts of a number of Arabic versions of Euclid's *Elements* and its

[a] Law, p. 60.

commentaries, geometrical works of Archimedes and several standard treatises on arithmetic and algebra in different libraries in India.[a]

Thus we have in the Bankipur library the *Sharḥ Uqlidas*, a critical commentary on Euclid's *Elements* in Arabic by Aḥmad b. 'Umar at-Karābīsī (*c*. A.D. 840), a distinguished mathematician of the Middle East and author of several works. Of the several works produced by Abū-l-Ḥasan Thābit b. Qurra (d. A.D. 901), a few noticed in Indian libraries include the *Kitāb Arshīmīdas fi'd-Dawā'iri'l-Mutamāssah*, the *Kitāb Arshīmīdas fī Uṣuli'l Handasah*, both geometrical works by Archimedes, and the *Uqlidas*. Thābit b. Qurra, besides being a physician, mathematician and astronomer of repute, was one of the greatest translators from Greek and Syriac into Arabic. In mathematics his favourite originals were the works of Apollonius, Archimedes, Euclid and Ptolemy. His works revived, in particular, the study of parabolas, paraboloids and amicable numbers. Mention may be made of *Ar-Risālah fī Auna'l-Ashkāla Kullahā mina'd-Dā'irah*, a work on the geometry of circles by Naṣr. b. 'Abdullah (*c*. tenth century) who flourished in Baghdad.

Next we turn to Abū Bakr M. b. Ḥasan al-Karkhī (d. *c*. A.D. 1019 to 1029), a contemporary of Śrīdharācārya, and one of the greatest Muslim mathematicians. A copy of his famous algebra *Kitāb al-Fakhrī fī-l-Ḥisāb Jabr-i-Wa'l-Muqābilah* has turned up in the library of the Osmania University. Largely based on Diophantos, *al-Fakhrī* deals with quadratic equations and equations of higher powers of the type

$$x^{2n}+ax^{n} = b,$$

of which he was the first to have given the solutions. He gave the summation of the squares and the cubes of natural numbers as follows:[b]

$$\sum_{1}^{n} i^2 = \left(\sum_{1}^{n} i\right)(2n+1)/3$$

$$\sum_{1}^{n} i^3 = \left(\sum_{1}^{n} i\right)^2$$

Unlike other Arabic mathematical works al-Karkhī's were free from Hindu elements.

Of al-Bīrūnī's (973–1048) mathematical works we possess his *al-kitāb fī Istikhrāji'l-Autār fi'd-Dā'irah bi-Khawāssi'l-Khaṭṭi'l Munḥani'l-Wāqi'fihā*, a treatise on the chords of a circle, *al-Maqālah fī Rāshikāli'l Hind*, an arithmetical work on the rule of proportions based on Hindu works, and *Riyāḍatu'l-Fikr Wa'l-'Aql*, a general work dealing with typical mathematical problems. Al-Bīrūnī's refinements in trigonometry and his construction

[a] A manuscript survey has been carried out by the Medieval Unit of the History of Sciences under the Indian National Science Academy, a preliminary draft of which has been made available to the author for use in this section.

[b] Sarton, I, pp. 718–19.

of accurate sine tables from 0° to 90° at the intervals of 15′ are well known. In this connection he also gave several trigonometrical relations. Accordingly, a special importance attaches to his treatise on the chords among the Indian collection of his mathematical works.

The same is true of 'Umar b. Ibrāhīm al-Khayyāmī's *Maqālah fī-l-Jabr-i* (*c.* A.D. 1110), one of the greatest medieval works on algebra. Important features of 'Umar's algebra are: an admirable classification of equations, geometric and algebraic solutions of quadratic and higher power equations, development of binomial series with positive integral exponents, geometrical postutates, etc. His classification of equations was based on the number of terms, e.g. trinomial, quadrinomial, etc. He made significant contributions to the solution of cubic equations which he arranged in 27 groups. The following are a few examples of his quadrinomial cubic equations:

$$x^3+bx^2 = cx+d$$

$$x^3+cx = bx^2+d$$

$$x^3+d = bx^2+cx$$

'Umar solved the above types of equations by finding the intersection of the conics. Such geometrical methods of solving algebraic equations paved the way for the development of analytical geometry at the hands of Descartes in the seventeenth century. In Europe, Renaissance mathematicians like Scipio del Ferro (1465–1526), Tartaglia (1500–57) and Cardano (1501–76) succeeded for the first time in solving cubic equations.

An arithmetical treatise *Ghunyatu'l-Hussāb fī 'Ilmi'l-Ḥisāb* by Aḥmad b. Thābit (*c.* twelfth century) who flourished somewhere in the Middle East is noticed in the Bankipur collection. The work deals with multiplication, division, ratio and proportion, extraction of roots, transactions, mensuration and excavation problems. Treatment of conic sections forms part of his mensuration. The author's another arithmetical work was *'Umdatu'r-Rā'id.*

Abū Ja'far Nāṣīr-al-dīn al-Ḥasan aṭ-Ṭūsī (1201–74) of Khorasan, the celebrated mathematician, astronomer and founder director of the Marāgha Observatory, was the most popular authority among the Muhammadan scientific circles, particularly in the days of the Mughal rule. His *Taḥrīr-u Uqlidas*, Arabic version of the *Elements*, is available in manuscript copies in several libraries, being published from Calcutta in 1824. *Taḥrīr*, as Thomas Heath pointed out, was not a translation of Euclid's text but a rewritten Euclid based on the older Arabic translations.[a] Jagannātha's Sanskrit translation was based on this Arabic version. His other works of which manuscript copies have been found in India include *Maqālah-i-Arshīmīdas fī Taksīri'd-Dā'irah* and *Kitābu'l-Kurah*

[a] Heath, I, p. 78.

Wal-Usṭuwānah, both based on Archimedes' geometrical works, and another tract on conic sections *Ar-Risālatu'l-Qiṭā 'fī 'Ilmī'l-Handasah.*

Finally we shall mention two works, both on arithmetic, of which several copies are available in Indian libraries. The *'Uyūn'l Ḥisāb* by Zainu'l-'Ābidīn (*c.* A.D. 1460) treats, among others, of the arithmetic of whole numbers, fractions, mensuration, solution of unknown quantities by the method of *Khaṭā'ain* and algebra. Bahā'u'ddīn al-'Āmulī (1547–1621) of Iran wrote an excellent arithmetic *Khulāṣatu'l-Ḥisāb*, of which several copies are available in Indian libraries. The work was published from Calcutta in 1862, the Arabic text with a German translation by Nesselmann appeared from Berlin in 1843 and a French translation by Marre from Rome in 1864.

WORKS BY INDIAN MATHEMATICIANS

The rich storehouse of Arabic and Persian mathematical literature was thus available to the Indian Muslims for a long period of time. They had also access to Hindu works in Arabic translations and commentaries as well as in their originals whenever they cared for them. But their own production, either in the form of original work or commentaries, appears far from impressive. Only from the sixteenth century do we notice some degree of activity resulting in the production of a few commentaries and translations.

In 1555, Abū Isḥāq b. 'Abdu'llāh, a mathematician of Golkonda, wrote *Sharḥu'sh-Shamsīyah* as a commentary on an arithmetical work *ash-Shamsīyah* by Hasan an-Nīshāpūrī, a pupil of aṭ-Ṭūsī. In 1587, Abū'l-Faiz Faizī, the poet laureate of Akbar, translated the *Līlāvatī* into Persian. For a Persian translation of Bhāskara's *Bījagaṇita*, the Muslim scholars had to wait for about half a century. In 1634–35, 'Aṭau'llāh Rashīdī, son of Ustād Aḥmad Nādir, who took part in the construction of the Taj, rendered this service. Mīr M. Hāshim b. Qāsim al-Ḥusainī wrote a commentary entitled *Sharh Taḥrīr-u-Uṣūli'l-Handasah Wa'l-Ḥisāb* on aṭ-Ṭūsī's geometrical work *Taḥrīr-u-Uṣūli* (1635). *Badāi'ul-Kanūn* (1663–64) by Medhnī Mal b. Dhram Dās Nārain b. Klliyān Mal Kāysth is an arithmetical treatise based on Bhāskara's *Līlāvatī.* In 1684, Ismatu'llāh as-Sahāranpūrī wrote a treatise entitled *Ḍābiṭ Qawā'idu'l-Ḥisāb* in which both arithmetical and algebraic problems were treated. Bahāu'ddin al-Amuli's arithmetic *Khulāṣatu'l-Ḥisāb* was commented upon in the seventeenth century by Luṭfu'llāh Muhandis in his *Sharh Khulāṣatu'l-Ḥisāb* and in the eighteenth century (A.D. 1770) by Amīnu'ddīn al-Lāhorī in his *Lawāmi'ul-Lubāb fī Sharḥ Khulāṣatu'l-Ḥisāb.* Towards the end of the eighteenth century (A.D. 1797) Faridu'd-Dīn Aḥmad Khān Bahādur, Superintendent of Mādrasah 'Āliyah and holder of important political appointments, wrote a work on geometrical compass entitled *Dar Ṣan'ati-Parkār Ma'Fawā'idu'l-Afkār.*

INTERRELATIONSHIP BETWEEN INDIAN AND GREEK, ARABIC AND CHINESE MATHEMATICS AND THE PART PLAYED BY INDIAN MATHEMATICS IN EUROPEAN RENAISSANCE

Situated geographically in the centre of the old world, India was from the beginning destined to play an important role in the transmission and diffusion of scientific ideas. In this diffusion mathematics formed no exception. Commercial and cultural contacts of India with Western Asia and Egypt extend to prehistoric times. The Persian Empire under Darius served as a bridge between India and Western Asia with its numerous settlements of the Ionian Greeks. Alexander's invasion and the founding of the Bactrian Greek kingdoms on the borders of, and within, India provided a further opportunity of intensification of East-West relationships. Ptolemy's Alexandria evinced great interest in establishing commercial contacts with India, an interest which was transformed into a practical reality through Rome's eastern policies. The Sino-Indian intercourse depended partly on the thriving trade along the silk roads, but largely on the spread of Buddhism into China. The rise of Islam and its bid for political and intellectual supremacy provided yet another opportunity for the appreciation of Indian sciences, particularly mathematics and astronomy, in West Asia, North Africa and in Spain.

The Indian emphasis on arithmetic and algebra is often contrasted with the Greek preoccupation with geometry. Nevertheless, the close similarity between the philosophical and mathematical writings of Pythagoras and his school on the one hand and the Vedic Hindus on the other has never failed to attract the attention of scholars. Leopold Von Schroeder, in one of his exhaustive studies, tried to show Pythagoras' indebtedness to India in respect of (1) his doctrine of transmigration and metempsychosis, (2) irrational numbers, (3) the theorem known after his name and (4) the doctrine of five elements.[a] Regarding Pythagorean geometry and irrational number, Schroeder held the view, shared by Garbe, Hopkins and Macdonell, that the square relation among the sides of a right-angled triangle and the concept of irrational numbers ultimately had their origin in the *śulba-sūtras* of Baudhāyana and Āpastamba. Others, notably Keith, have disputed such views.

As to Sino-Indian intercourse in mathematics, the catalogue of the Sui dynasty listed a number of Brāhmaṇical works, such as *Po-lo-mên Suan-fa* (Brāmaṇical methods of calculations, in 3 books), *Po-lo-mên-wen-ching* (Brāhmaṇical astronomy, in 21 books) and a number of similar Hindu astronomical tracts already referred to. The establishment, in the seventh century A.D., of an Astronomical School or Board in Chang-Nan for the propagation of Brāhmaṇical astronomy and the reform of the calendar after the Hindu model, played an important part in transmitting Hindu mathematics in China. In the eighteenth century, during the Thang times, Ch'u-t'an Hsi-ta (Chinese version of Gautama Siddha or Siddhārtha),

[a] Sen (S. N.) (3), pp. 8–30.

translated a Sanskrit calendar under the Chinese title *Chiu-Chi-li* in which were discussed, among others, the Indian decimal notation and arithmetical rules. It is further on record that the Tantric-Buddhist astronomer I-hsing was ordered by the emperor to investigate the chronological and arithmetical ideas introduced to China from India by Ch'u-t'an Hsi-ta. Sarton observes: 'The Chinese treatises of Ch'u-t'an Hsi-ta and I-hsing are of special value as witnesses of the penetration of Hindu mathematics into China. It is possible that the Hindu numerals were introduced into China at this time, though we have no positive evidence of it.'[a] Writing about the arithmetical computations employed by Hsi-ta in his calendrical work, Mikami informs us that the technical terms used therein 'were so peculiar that the Chinese scholars who are ever fond of following conservative tendencies were little able to understand its contents'.[b] He further observes: 'The employment of the symbol 0 for zero or for the digit that is wanting was probably derived from this translation of an Indian calendrical treatise, or from some other Indian source. This employment does not, however, occur until the middle of the thirteenth century, so far as we are informed.' Studies in other areas, such as the problem of the circle-measurement and accurate determination of the value of π, appear for the first time in China after her contact with Indian civilization.

Kaye has cited a number of parallel examples occurring simultaneously in the Chinese and the Indian mathematical texts. The Chinese arithmetical classic, *Chiu Chang Suan Shu* (Arithmetic in Nine Sections) (second century B.C.), gives the area of the segment of a circle in a form which is also found in Mahāvīra's work (*c*. A.D. 830). The following problem on right-angled triangle given in the same work appears in Hindu works after the sixth century A.D.: 'There is a bamboo 10 feet high, the upper end of which being broken reaches to the ground 3 feet from the ground. What is the break?' The remainder problem, without any rule for solution, appears in the *Sun-Tzu Suan-Ching*, another arithmetical classic (fourth or fifth century A.D.), a little earlier than such examples are met with in the Indian texts. The rules for solving such remainder problems, or what is the same thing as the solution of indeterminate equations of the first degree, appear in Indian texts from the time of Āryabhaṭa much earlier than they do in the Chinese works. Accordingly, questions of borrowings on the ground of chronological lag, although tempting, cannot be decided for certain. From the scanty materials that have survived so far it is safe to say that it was by no means a one-way traffic and the mathematical advancement of the one stimulated that of the other.

The part played by India in Arabic literary renaissance is well known. When the Arabs, after their successful military conquests of the Middle East and North Africa, set themselves upon the intellectual conquest, they first turned their attention to the Persian literature of the Sassanian Empire.

[a] Sarton, I, pp. 504, 513, 514. [b] Mikami, p. 59.

Their interest in astronomy was roused by a Persian work on astronomy, *Zīj-ashshahriyar*, which was largely a book of tables based on astronomical observations carried out in the Sassanian period. This *Zīj* itself was based on Indian elements, and it was felt necessary to study Indian astronomy in detail for a better understanding of the work. An opportunity presented itself when, during the reign of the second Abbāsid Caliph al-Mansūr (753–774), a direct contact with India was established through the Arab territory of Sind. Al-Adamī reports that an Indian astronomer visited the court of al-Mansūr and discoursed on Hindu astronomy. Abu-Māshar, an astrologer from Balkh, acknowledged his debt to India in obtaining his knowledge of the Hindu great cycles. Obviously, these early contacts were very useful, for shortly thereafter a number of Arab astronomers were commissioned to translate into Arabic Brahmagupta's *Brāhmasphuṭa-siddhānta* and *Khaṇḍakhādyaka*. Muhammad ibn Ibrāhīm al-Fazārī (d. 796 or 806) and Ya'qūb ibn Ṭāriq (d. 796) produced these translations with the assistance of Hindu pandits. Sarton suggests that these translations were possibly the vehicle by which Hindu numerals were transmitted to the Arabs.[a] Most probably, the knowledge of Hindu numerals and number-writing had spread to Western Asia much earlier, as in the seventh century Severus Sebokht, a Christian monk, already mentioned in appreciative terms the Hindu numerals.

The next important figure in the transmission of Hindu astronomy and mathematics among the Arabs was al-Khwārizmī, one of the greatest mathematicians of his time. Al-Khwārizmī developed a great liking for Indian mathematics and astronomical system, learnt Sanskrit, prepared an abridged version of *Sindhind* (Arabic title of *Brāhmasphuṭa-siddhānta*) and wrote an arithmetic explaining the Hindu system of numeration. His algebra was also inspired by his Indian studies. Indian studies were so fashionable at his time that a number of his notable contemporaries also participated actively in this work of transmission. Thus al-Kindī wrote four books on the use of the Hindu numerals and computation *Hiṣābu'l hindi*; Ḥabash al-Ḥāsib, al-Nairizi, al-Ḥasan ibn Miṣbāḥ and ibn al-Adamī constructed astronomical tables on Hindu astronomical model. In the eleventh century al-Bīrūnī revived Indian studies with fresh energy and thoroughness, himself checking corrupt translations of the previous generations, producing new translations and critical studies of various aspects of Hindu mathematics and astronomy. On Hindu numerals, his was the best medieval account.

There is no doubt that Indian mathematical elements, particularly arithmetic based on decimal place-value numeration, passed into Latin Europe in the course of transmission of Arabic mathematical knowledge there. The leaders of this transmission were, among others, Adelard of Bath (*c.* 1142), John of Seville, Robert of Chester, Villedieu, Sacrobosco and Leonardo Pisano.[b] At this time and up to a much later date, the

[a] Sarton I, p. 530.

[b] Sen (S. N.) (6), pp. 55–59.

abacus of Gerbert was in general use for all calculations and counting purposes. Adelard (*c.* 1142), English philosopher, mathematician and scientist, was probably the earliest Latin exponent of Hindu arithmetic, trigonometry and astronomy through his translations of al-Khwārizmī's mathematical and astronomical works. He probably translated an arithmetical work attributed to al-Khwārizmī under the title *Liber ysagogarum Alchorismi.* But the earliest Latin version of al-Khwārizmī's arithmetic *Algoritmi de numero Indorum*, of which the Arabic version is lost, is due to an unknown translator. Hispano-Jewish John of Seville (*c.* 1135) wrote *Liber algorismi*, an arithmetical work which, although based on al-Khwārizmī, drew upon other Arabic sources. Robert of Chester (*c.* 1141) introduced the study of algebra in Latin Europe by his translation of al-Khwārizmī's *Hiṣāb al-jabr wal-muqābala* which bears the impress of Hindu algebraic thought. Villedieu's (Alexandre de Villedieu, d. 1240) *Carmen de algorismo*, composed in hexameter, closely followed John's *Liber algorismi.* Translations of *Carmen* into English, French and Icelandic, several commentaries on it and a large number of manuscript copies found in the libraries of Europe bear testimony to the influence it exerted and the wide circulation it enjoyed in the thirteenth century. The work possibly played an important role in the diffusion of Hindu numerals in Latin Europe. Villedieu's contemporary John Sacrobosco's *Algorismus Vulgaris*, another arithmetical tract, also enjoyed great popularity. Another date often taken to be the starting point of European mathematical renaissance is 1202 in which year appeared Leonardo Pisano's arithmetical classic *Liber abaci*, containing probably the first complete exposition in Latin of Hindu and Arabic arithmetic, including decimal place-value numeration.

This is the background of the introduction into Europe of the new arithmetic, called 'algorism', based on decimal place-value numeration. In time algorism became one of the active promoters of the Renaissance itself. This is corroborated by the sudden appearance in quantity of printed arithmetical works from the sixteenth century in several European countries. To mention a few, in Italy, Cardano's *Practica arithmetice et mensurandi singularis* appeared in 1501 and Tartaglia's *La Prima Parte del general trattato di numeri e misure* in 1556. In England, Robert Recorde's *The grounde of artes, teachyng the worke and practise of arithmetike* was reprinted seventeen times before 1601 and Digg's *Stratiotios* appeared in 1579. In Germany, the arithmetical movement was led by Jacob Köbel, author of *Rechenbiechlin* (1514), Stifel, author of *Arithmetica integra* (1514), and Christopher Clavius, author of *Epitome arithmeticae practice* (1583). In France, Boissière's *L'art d'arythmétique* (1554) and Forcadel's *L'Arithmétique* (1556–57) helped popularize arithmetic. Elementary as these arithmetical tracts may now appear, their potentialities were soon felt in the rising trade and commerce of the Renaissance period, in the teaching programmes of universities and schools and in the higher pursuits of mathematics in general.

4 MEDICINE

R. C. Majumdar

ĀYURVEDA: ORIGIN AND ANTIQUITY

Medicine is a natural art born out of the instinct of self-preservation. As in every other land, medical knowledge in India must have grown out of the sheer necessity of overcoming injury, sickness and pain. This overpowering compulsion also made man give up the indiscriminate use of raw vegetation and meat from all sources in favour of selective cultivation, husbandry, processing, mixing and cooking. The prehistoric art of selecting substances which could be assimilated by the human system with benefit and their cooking and compounding to give the most of nourishment and health forms integral parts of the indigenous medical science of India, known as the *Āyurveda*. The term *āyus* means duration or span of life; *veda* means unimpeachable knowledge. Hence the *Āyurveda* is concerned mainly with prolongation of healthy life and prevention of disease and senility and only secondarily with curing of disease. The common translation of the *Āyurveda* is 'science of life'. Surgery is another survival skill which is as old as hunting and warfare.

The growth of the healing art is a part of the natural process of man's adjustment to his environment, and the origin of the *Āyurveda* cannot be credited to any particular age, place or person, despite many legends to the contrary. Such legends describing a divine origin and corresponding antiquity of the *Āyurveda* are found in the introductory passages of many Āyurvedic texts, e.g. the *Caraka*, the *Suśruta* and other *Saṃhitās*. It is recorded that Brahmā (the creator) was the divine source of this science, which was brought into existence before the creation of mankind. The knowledge passed from him to the god Dakṣapati, then to the two celestial physicians (the twin Aśvinakumāras), later to Indra, the god-king, and finally to Bharadvāja, the semi-divine sage. Bharadvāja taught this science to a conference of sages meeting somewhere in the Himalayas with the common objects of alleviating human suffering and assuring a long, healthy and satisfactory life to all human beings. The same or similar legends are found in many works, sometimes in greater details. But these legends hardly possess any historical value.

As far as recorded knowledge goes, the earliest instances of rational medical knowledge are to be found in the *Ṛgveda* and the *Atharvaveda*, both of the second millennium B.C. But there is much evidence to show that the *Āyurveda* was preceded by an earlier medical knowledge developed by the builders of the Indus civilization. The Aryans developed it by taking up the beliefs and practices of the 'black-skinned indigenous people', speculating and experimenting freely in their own way, learning much and unlearning only that which was patently wrong.

REMNANTS OF PREVIOUS TRADITIONS

The medical knowledge of the pre-Aryan Indians has been so thoroughly mixed, diluted and absorbed into the Āyurvedic system that it would be an almost hopeless task to attempt to separate the earlier knowledge which survives only in some *tantras* and in the non-Āyurvedic medicine still practised by otherwise ignorant medicine men throughout India, employing inorganic remedies, secret herbs, animal products and venoms. In the beliefs and practices of the primitive aboriginal tribes of India also, a storehouse of this ancient knowledge can be discerned. The reputation of medical skill possessed by nomadic gypsy tribes, which spread from India into Europe and the Mediterranean lands in early times, can also be attributed to this primitive knowledge. Some examples of ancient Drāviḍa medical lore are believed to have survived intact without debasement in the non-Āyurvedic systems of medicine still surviving in parts of south India, and are found codified in existing treatises in Tamil and other south Indian languages. The fragmentary remnants of *Agadatantra* (use of poisons and venoms in curing diseases, and treatment of bites of poisonous animals and poisonings) found in various ancient works and of *Bhūtavidyā* (black magic and treatment of mental diseases and possessions) found in Vedic lore and in Āyurvedic treatises, as will be discussed later, testify to the existence of lost branches of non-Āyurvedic medical knowledge incorporated in the *Āyurveda*. In the *Rāmāyaṇa*, Rāvaṇa, the demon (non-Aryan) king, is said to be a master of many sciences including medical science; and the prince Lakṣmaṇa is resuscitated from a mortal injury by the medical skill of the apes, that is dark-skinned aborigines (6th canto; Lakṣmaṇa, already dead by the *śaktiśela*, is revived by a rare plant prescribed by a learned doctor from among the apes).

ARCHAEOLOGICAL EVIDENCE

We know a great deal of pre-Aryan civilization, going back to the third millennium B.C., from the archaeological excavations at Mohenjo-daro, Harappa and many other sites in the Indus valley and in many other regions outside it. The discovery, in these sites, of manufactured implements and other objects of metals and alloys, glazed and decorated pottery and figurines,

bricks made in kilns and engravings in precious stones, indicates a high level of knowledge of the physical and chemical sciences, likely to be matched by a similar knowledge of medicinal drugs and compounding. This is no doubt a mere conjecture, but the existence of a high level of social sanitation and of public hygiene in these communities is fully borne out by archaeological findings. Of the broad facts of town-planning, use of kiln-bricks, paved streets, municipal water-supply and drainage systems, public baths and hydropathic establishments and sanitary installations in private houses, there is abundant evidence. Water-proofed walls of baths lined with impervious bitumen, arrangements for draining and refilling public bathing tanks through conduits, enclosed bathrooms and water-closets made of brickwork connected with central water-supply and drainage, rubbish chutes emptying into external masonry receptacles (presumably cleared on a municipal basis), an efficient and elaborate drainage system running beneath the paved streets, spaced brickwork manholes of drains with removable lids, and soak-pits suggestive of sanitary privies of modern invention, all show a remarkably high level of public health activity and universal consciousness of sanitation without parallel in contemporary civilizations and, in fact, most other civilizations of historic times.

It is invariably true that social medicine develops in any country only after a fairly high level of medical knowledge has already developed, which must have been the case with this ancient civilization of India. It is also true that the extensively studied archaeological remains of contemporary and comparable river-valley cultures in Egypt, the Middle East, China and Central America show no public sanitation comparable to the findings described above. Though this constitutes no real unassailable proof, the natural inference is that the medical knowledge of this early phase of Indian civilization was superior to, or at least comparable with, what obtained elsewhere in the contemporary world. The preserved specimens and written records in the form of hieroglyphics (which have been deciphered) of ancient Egypt show a knowledge of medicine which can compare with later Greek, Roman, Arabic and medieval European civilizations. Unfortunately, the large mass of pictographic characters on the seals and potteries of the Indus civilizations still awaits deciphering and we must wait for future success in this work—or another lucky Rosetta stone—to give us more data on the state of medical knowledge of the Indus valley and allied cultures.

As mentioned earlier, the beginnings of the *Āyurveda* may be traced first in the *Ṛgveda* and then in the *Atharvaveda*; its nature and progress will be discussed in the next sections of this chapter. Both in its development, as also in the production of the famous medical compendiums of the later period, the methods and practices of the earlier period typified by the Indus civilization, it is reasonable to believe, exerted no mean influence.

INDIAN MEDICINE IN THE VEDIC PERIOD

THE CONCEPTION OF MEDICAL SCIENCE

The oldest ideas of the Aryans on cosmic forces, origin of life, birth, death, sickness, pain, happiness and salvation are revealed in the Vedic hymns where rational ideas and insight are found to be continuously crystallizing out of a matrix of ignorance and superstition, even in the earliest *Saṃhitās*. Interwoven with archaic concepts of diseases, both of the mind and the body, as manifestations of the wrath of gods for sins committed or as possessions by demons,[a] to be cured by propitiation, ritual practices, sacrifices or exorcism, sorcery or charms,[b] we find logical speculations on the origins of diseases, use of healing drugs, beneficial treatment and surgery. There is also the clear emergence of the conception of the healing art as not a mere skill but as a social system tolerating many other ingredients such as the powers of magic and suggestions, ideas gained by experience and experiments, the social value of health, compassion to human suffering, scientific tenets and philosophical speculations. It is from these nebulous beginnings that the Āyurvedic conception of medical knowledge as a comprehensive science and philosophy of life developed later.

During this period, the healing art was recognized as a part of the sacramental duties of the priests. The priest-sorcerers were the physicians, *par excellence*, though wandering medicine men, mentioned in the *Atharvaveda*, also practised medicine and surgery. The tradition of medicine as a part of the religious lore continued unbroken up to the later period of the Āyurvedic treatises, in which medical science is declared to be a *upāṅga* (part) of the *Atharvaveda*,[c] the physician a special votary of the same *Veda*[d] and also *Āyurveda* as an *upaveda* (secondary *veda*), forming part of the *Ṛgveda*.

The Aryans personified the natural and cosmic forces as gods, and their influence was considered supreme in causing and curing illness. Water was the primordial element of the Aryans. 'In the waters is the nectar of immortality, and in the water is the potent curative powers.'[e] Divinity was also conferred upon plants with healing powers. The hymn, *oṣadhistuti* (ode to the healing plants), is addressed to *soma*, the moon god and the divine ruler of plants, and also a terrestrial plant from which sacrificial liquor was prepared.[f]

An almost parallel conception of medicine is found in the sacred books of another branch of the Indo-Aryan community, the *Avesta* of the Iranians. The medical data of the *Avesta* are mostly found in the *Videvdat* dating from Vedic times. This book of the *Avesta*, also known as *Vendidād*, escaped destruction by Alexander the Great and was preserved in a Greek translation. The Spirit of Evil (*Ahira Mainya*) and other demons bring

[a] *AV.*, IV. 37. 10; VI. 20. 2; VI. 90; VII. 83; VIII. 2. 12.
[b] *AV.*, VI. 113. 1–10; *RV.*, VIII. 47. 13.
[c] *SS. Sū.*, 1. 3.
[d] *CS. Sū.*, 30. 20.
[e] *RV.*, I. 23. 19.
[f] *RV.*, X. 97.

all diseases which can be cured by exorcism, *mantras* (holy chantings), sacrifices of cattle, and also by *baesajas* (drugs).[a] Innumerable plants with healing powers are associated with the 'waters' (which is not only the primordial element but also a source of health) and with *haoma*, the liquor of immortality. The cosmic elements rule over the human body and cause its functions and malfunctions, the human body being the microcosm of the universe.[b] Three types of medicine men are distinguished; those who practise with the knife, with plants, and with holy words, the last class being the most esteemed.

ADMIXTURE OF RATIONAL IDEAS WITH PRIMITIVE SUPERSTITIONS

Anatomical and physiological terms, biological ideas, methods of treatment, and rudimentary theories on the origins of life and of diseases are scattered in the different works of Vedic literature in a remarkable admixture of accurate knowledge and rational ideas with superstitious beliefs and faith in the supernatural. This makes Vedic literature a rich storehouse both of medical knowledge and of the pseudo-medical ideas of the times. This was a twilight period for Indian medicine when scientific theories and progressive methods were struggling to emerge from a morass of primitive ideas and irrational rituals.

Though diseases and even accidents are attributed to supernatural causes, many passages indicate that illness may be due to other and natural reasons. A passage states that a disease can have one of the three possible origins, i.e. *abhraja* (from clouds or moisture), *vātaja* (from wind) and *suṣmaja* (from desiccating agents).[c] The term *pitta*, for the desiccating or the fiery principle, occurs in another passage of the *Atharvaveda*.[d] *Śleṣmā*, for the aqueous principle, occurs in the *Śatapatha Brāhmaṇa*. The term *tridhātu*, possibly referring to the three bodily humours, occurs in the earliest work, *Ṛgveda*. In view of the extreme importance of this reference, it may be mentioned that many European scholars, including Langlois, the translator of the *Ṛgveda*, Reinbold Müller and J. Filliozat, do not accept that the phrase *tridhātu śārma vahatam* refers to the bodily humours. But the ancient commentator Sāyanācārya has rendered *tridhātu śārma* as 'well-being of the three bodily elements' in the classical Āyurvedic sense, and this interpretation has been accepted by Wilson, Cordier, and Pauthier and Braunet. If the latter view is correct, this Vedic conception of the humoral theory antedates Greek ideas on the subject by at least one thousand years.

Diseases are also said to be caused by *kṣetriya* (congenital) factors or by infection,[e] by change of seasons, specially in the case of *takman* fevers which recur periodically,[f] and by *kṛmis* (minute insects living inside the body).[g]

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[a] *Videvdat*, XXII; VII. 44, 58; XX. 3.
[b] West, pp. 100 ff.
[c] Das Gupta, pp. 299 ff.; *AV.* I. 12. 3.
[d] *AV.*, XVII. 3. 5.
[e] *RV.*, X. 97. 1; *AV.* II. 8. 1; *AV.*, III. 7. 1–6; V. 30. 3; VI. 83. 1; VII. 76. 4.
[f] *AV.*, V. 22. 13; XIX. 39. 10; *Kauś. Br.*, V. 1; *Gop. Br.*, II. 1. 9.
[g] *AV.*, II. 31. 2–5; V. 2. 3.

Cures are effected by charms, imprecations against demons and sorcerers, sacrifices and propitiation of divine favour by the chanting of hymns and ritual practices. But a large number of plant remedies are recommended for curing diseases in many passages, mainly in the *Vājasaneyī*, *Taittirīya* and *Maitrāyaṇī Saṃhitās*. The metals gold and lead and some animal products are also used as healing agents. Sunlight, milk and milk products, honey, etc., are recommended in some passages for their therapeutic and nutritive values. Surgery and surgical methods are described for a number of conditions.

These contradictions of the primitive and the progressive, sometimes in the same hymns, no doubt indicate a transitional stage of medical knowledge, but some of the apparently irrational methods are possibly not as worthless as they appear at first sight. Vedic treatment often follows a set formula of propitiation of the angered gods, appeasement of malignant forces, magic formulas with the auxiliary use of material remedies like amulets, external applications and internal medicines. Along with this complex and concerted attack at many levels is a psychiatric approach in the shape of frequent appeals (by suggestions and mesmeric repetitions) to the patient who is constantly assured of progressive healing and ultimate cure. This psychosomatic view of physical as well as mental diseases and the deliberate employment of the combined mental resources of the healer and the patient were retained, though in a much modified form, in the later and more scientific system of Āyurvedic medicine.

Despite its deceptive primitive garb, its obsession with magic and religion and its heavy leaning on irrational methods, Vedic medicine contains so much of rational observations and inferences and so much accurate medical knowledge that it almost merits the name of a science. Different ailments affecting the head, eyes, ears, heart, lungs and stomach, skin diseases, urinary complaints, progressive emaciation (consumption), external and internal abscesses, jaundice, rheumatism and neuralgia are listed in the early Vedic texts. Some of the diseases named are: *ailava* (eye diseases), *alaji* (inflammation of the eyes), *akṣata* (rupture or ulceration of the lungs), *apaci* (scrofula), *arśa* (piles), *āsrāva* (formation of pus), *balāsa* (chronic asthma or bronchitis), *harimā* (jaundice), *hṛdroga* (heart diseases), *hṛdyota* (malfunctioning of the heart), *jāyānya* (a type of consumption), *karṇaśūla* (earache), *kāśika* (chronic cough), *kilāsa* (leprosy), *kuṣṭha* (persistent skin diseases), *rājayakṣmā* (severe and progressive wasting disease), *sikatā* (calculi), *śīrśakti* (headache), *śīrṣāmaya* (diseases of the head), *takman* (fevers), *udara* (dropsy), *visarpa* (extensive skin eruptions), *visalyaka* (neuralgia), *viṣkandha* (rheumatism), *yakṣmā* (consumptive conditions), etc. Due to semantic reasons the English equivalents are subject to mistakes, and are at best approximate. In some cases their symptoms are described.

The *saṃhitās* also name nearly 300 limbs and inner organs of the body of which a complete list is given by Filliozat.[a] The birth of a baby is described in the *Atharvaveda* and the physician is recommended, in case

[a] Filliozat (2), pp. 144 ff.

of complications in delivery, to operate upon the *mehana* (birth channel), *yoni* (womb) and *gavīnaka* (connecting canal).[a] Other surgical processes described or mentioned are incisions for boils, surgical relief of angry swellings caused by imbedded arrows, etc.,[b] treatment of fractures,[c] use of a reed as catheter to relieve painful or blocked urination,[d] surgical removal of an injured eyeball[e] and the replacement of a leg amputated in battle by an iron limb.[f] The last reference may be metaphorical rather than actual.

The idea of rejuvenation (of the ageing body and its faculties) is first found in the *Ṛgveda*. *Āyuṣyāṇi* (measures and treatment aimed at maintaining perfect health of mind and body and also promoting *longevity*) is one of the twin aims of medical science according to the *Atharvaveda*, the other being *bhaiṣajyāṇi* (curative treatment by medication). Hygiene and dietetics are considered integral parts of medical knowledge and many passages are devoted to the preventive aspect of medical science. Milk is said to confer strength, nutrition, intelligence, brightness of complexion and also to help proper growth of the foetus, and hence recommended for the pregnant woman.[g] The benefits of *surā* (alcoholic beverages) and of *madhu* (honey) are also described in many hymns. Rice of good quality taken as a cereal is said to improve vital capacity and help infants to grow their milk teeth.[h]

There is no attempt to classify the anatomical and physiological information nor are the diseases classified according to any scheme. There is, however, a rudimentary attempt at symptomatic treatment, the drug administered being chosen with an eye to its supposed ability of making good the visible deficiency.

MEDICAL KNOWLEDGE IN LATER VEDIC TEXTS

The medical references in the earlier *saṃhitās* are casual and fragmentary, but the later Vedic works are distinguished by a search for order and by speculations about origins and underlying causes. A number of passages contain plausible theories about the composition of living and non-living matter, the biological functions, the relationship of the *śarīra* (human body and organism) to its environment, the nature of the vital and motive forces in a living body, and other matters. The theory that the same five elements, *pṛthivī* (earth or solid), *apas* (water or liquid), *vāyu* (air or gas), *jyoti* (fire or radiant energy) and *ākāśa* (ether or empty space), constitute the human body (microcosm) as well as the macrocosm is accepted as axiomatic truth in many passages.[i] Life in its various manifestations is said to have three possible types of origin, *aṇḍaja* (oviparous), *jarāyuja*

[a] *AV.*, I. 11.
[b] *AV.*, VII. 78. 1.
[c] *AV.*, IV. 12. 1, 2 and 7.
[d] *AV.*, I. 3.
[e] *RV.*, I. 116. 16.
[f] *RV.*, I. 116. 15.
[g] *RV.*, I. 187. 9; *Taitt. S.*, VI. 2. 5. 3.
[h] *AV.*, IV. 35. 5; VII. 140. 2.
[i] *Ait. Br.*, ii. 3. 2. 2; *Ait. Up.*, iii. 5. 3; *Kauś. Ar.*, vii. 2. 2; *Tait. Up.*, iii. 2. 1.

(viviparous) and *svedaja* (born by combined effect of warmth and moisture).[a] The *vāyu* (wind) in the human organism is classified into five types according to physiological locations and functions, and the idea of identifying *vāyu* with the nervous system (with motor and sensory functions and control of the seat of consciousness as well as the involuntary muscles) is clearly discernible.[b] Physiological data, presumably obtained by dissection, are found in many passages. The human body is supposed to contain, dispersed in all its parts, 100 *dhamanīs* (major blood-carrying tubes), 1,000 *hirās* (minor veins, etc.),[c] 72,000 *hitas* (extremely minute capillaries)[d] and 10,800 *pesas* (muscle-fibres).[e] The therapeutic values of milk and milk products are described in the later Vedic texts also; milk compounded with turmeric is recommended for jaundice;[f] freshly churned butter is said to be of great dietic value to children and pregnant women, but clarified butter is recommended for healthy adults;[g] clarified butter mixed with various drugs is given for preventing miscarriage.[h]

Some surprisingly advanced theories and valid observations are found in a work styled *Garbha Upaniṣad*, the antiquity of which has been doubted by many scholars. The suspect passages may also have been interpolated at a later date. It contains, among other things, a detailed description of the periodic changes which occur in the foetus during the period of gestation, a theory of metabolic changes occurring in the body and a list of the six different tastes, seven body elements (blood, flesh, fat, connective tissues, bones, marrow and semen) and three waste products (stool, urine and sweat). Even if this last evidence is ignored, Vedic literature furnishes us with an array of medical facts and theories which are impressive, considering their antiquity. This knowledge must have served as a valuable source material for the later science of *Āyurveda*. In fact, many of the physiological ideas are retained with modifications and elaborations in the latter.

MEDICINE IN BUDDHIST LITERATURE

The fundamental conceptions and observations on different subjects, scattered pell-mell in Vedic literature, were collected together under appropriate titles from the sixth century B.C. onwards in separate texts known as *sūtras*.

Erudite and comprehensive treatises were also written on most of the subjects, and a part of this vast literature survives up to the present time. Followers of all religious faiths—Brāhmaṇas, Buddhists, Jains and others—contributed to this specialized literature. In medicine, the contributions of Buddhist scholars are of great significance and outstanding value. Nāgārjuna the medical author, the later Nāgārjuna (who composed

[a] *Ait. Up.*, iii. 5. 3.
[b] *Bṛh. Up.* iii. 2. 2–8; *Chānd. Up.*, iii. 13. 1–5; v. 19. 23; *SS. Sū.*, **15**. 1; *SS. Ni.*, **1**.
[c] *AV.*, I. 17. 1; VI. 90. 2.
[d] *Bṛh. Up.*, ii. 1. 19.
[e] *Gop. Br.*, i. 5. 5.
[f] *Kauś. Sū.*, xxvi. 17.
[g] *Ait. Br.*, I. 1.
[h] *Kauś Sū.*, xxv. 12. 23.

many treatises on *rasacikitsā*, metallurgy and alchemy), Vāgbhaṭa, many of the Siddha authors of the iatrochemical school, and nearly all the medical missionaries who carried Indian medical science into Tibet, Central Asia, China and Ceylon were followers of the Buddhist faith. The contributions of the Buddhist scholars contain no new features differing basically from other works. In medicine, as in other branches of knowledge, there was no division on the basis of religion, for the Buddhists of these centuries were not an isolated community but characteristically and completely Indian in outlook.

Some of the Buddhist canonical literature contain medical information interwoven with religious matter. The *Bhaiṣajyavastu*, forming part of volume 3 of the *Gilgit Manuscripts*, gives instructions regarding the use and dosage of medicinal drugs, classification of plant drugs, the useful parts of various plants, etc. But these follow Āyurvedic tenets and are of no special value. The *Cīvaravastu* (Part 2, volume 3 of the *Gilgit Manuscripts*) contains a long passage on the medical training of Prince Jīvaka (physician of King Bimbisāra, a contemporary of Gautama Buddha) and some marvellous cures effected by him. If the information in this work is accepted at its face value, difficult surgical operations called *kapāla mocana* involving removal of a portion of the skull and reaching the brain inside, eye surgery, curetting of the cervical region, removal of vaginal tumours, as also medical treatment of dropsy, internal tumours, varicose veins, eye diseases, etc., must have developed at this early age. The medical stories found in the *Cīvaravastu* and other Buddhist canonical works may not be true in all details, but they certainly give us an idea of the degree of knowledge—actual and probable, real or hypothetically possible—current at the time when these texts were composed, i.e. two or three centuries before the Christian era.

Very interesting information is given about Jīvaka besides the above details of medical cure. He studied medicine at Taxila under a world-renowned physician for the prescribed period of seven years. But, before he was given the licence to practise medicine, he had to undergo a sort of practical examination prescribed by his teacher, who directed: 'Take this spade and seek round about Takṣaśilā a *yojana* on every side, and whatever plant you see which is not medicinal, bring it to me.' After a good deal of botanical investigations, Jīvaka could not discover any plant that was devoid of medicinal properties. The teacher was satisfied and gave him a little money with leave to go home and practise as a physician.[a] This story implies a current belief that all plants as well as reeds, water, stone and metals possess medical value, i.e. potentiality of healing. The same idea is found in the *Caraka Saṃhitā* which states that 'each and every substance, due to its inherent and specific properties, can be utilized in some disease or other'.[b] Jīvaka also learnt the great value of meticulous observation and of valid deductions based on such observations. By

[a] Majumdar (R. C.), II, pp. 276–77. [b] *CS. Sū.*, 26. 12, 29.

observing the area over which an elephant had passed earlier, he was able to give many details about the animal and its rider and to correlate his deductions with details considered unimportant by others. This anecdote points out the value of accurate observation and deductions in the medical profession. Jīvaka also learnt that erudition and skill in the science of medicine should not merely lead to a lucrative practice but should be taught to others in order to benefit humanity.

ĀYURVEDA: THE SPECIAL TREATISES

ĀYURVEDIC *SAṂHITĀS*

Āyurveda had its origin in the healing art of the Vedic period. Its development as a comprehensive and rational medical system came in the succeeding centuries side by side with the flowering of the philosophies, arts and sciences in the golden age of Hindu civilization. Our knowledge of this ancient science comes mainly from the surviving written treatises, the oldest of which are the *saṃhitās* named after Bhela (or Bheḍa), Caraka and Suśruta. The first has reached us in a single and very incomplete manuscript but many independent references in other ancient works as well as the internal evidence put its authenticity and antiquity beyond reasonable doubt. It is very possibly the oldest medical treatise in existence. Nagnajit, an authority on toxicology, mentioned in the *Aitareya* and *Śatapatha Brāhmaṇas*, is also mentioned in this work as a contemporary living person.[a] This makes the original *Bhela Saṃhitā* a work of the period of the *Brāhmanas*. The work, as recent studies indicate, contains some valuable materials to fill up gaps in both the *Caraka* and *Suśruta Saṃhitās*; but on account of its fragmentary and mutilated character, it does not provide a full exposition of Āyurvedic medical knowledge.

The other two works now available as later redactions, respectively by Dṛḍhabala (eighth or ninth century A.D.) and Nāgārjuna (*c.* third century A.D.), of earlier works belong entirely to a different category. Both are erudite and exhaustive compendiums, incorporating and codifying the theoretical and practical knowledge of medicine and its contributory arts and sciences available at the times. The *Caraka* and *Suśruta Saṃhitās* were followed in later centuries by more sophisticated treatises, commentaries and medical encyclopaedias (which were largely based on materials obtained from the two earlier works), but they have retained their place during two millennia as the two most complete and representative works on *Āyurveda.* Most of our present knowledge of the extent and depth of Indian medical science is obtained from these two standard works.

By their own testimonies, the extant texts of the two great *saṃhitās* are revisions of the original with additions and alterations. There is evidence

[a] Sharma, (S. V.), pp. 228–30; *see Journal of Dept. of Letters*, Calcutta, 6, p. 30.

of many medical treatises which were composed before these two but are now quite untraceable, and each of these two names a particular earlier treatise on which it is based. Caraka's original was the *saṃhitā* of Agniveśa,[a] a disciple of the medical sage Ātreya. Long passages in the *Caraka Saṃhitā* are in the form of questions and answers between Ātreya and Agniveśa. This original *Agniveśa Saṃhitā* was referred to even so late as the eleventh century A.D. by Cakrapāṇi Datta in his *Āyurvedadīpikā*. In a similar way the *Suśruta Saṃhitā* contains a series of discourses between the holy sage Dhanvantari and his disciple Suśruta,[b] but much of the original material seems to have been revised by the redactor, Nāgārjuna, who has also made considerable additions to the text, according to the commentator Ḍalhaṇācārya.

CHRONOLOGY OF THE *SAṂHITĀS*

There is no reason why the given sequences of authorship and editorships should not be accepted as correct, but acute difficulty is encountered in providing the above-named persons with actual historical dates. There is a sage Ātreya in the *Ṛgveda*; another one of the same name was a famous medical teacher at Taxila at the time of Gautama Buddha; and two more are found in the *Caraka Saṃhitā*[c] itself; an Agniveśa is found in the *Mahābhārata* who is unlikely to be the disciple of Ātreya. Caraka is a class title of a school of physicians, existing from Vedic times,[d] and also the personal title of a physician in the court of King Kaṇiṣka,[e] and very possibly the title of many other physicians belonging to the same school of medicine. According to many commentaries by reputed Indian authors of the first millennium A.D. and later, Patañjali, the great philosopher and alchemist of early Buddhist times, was identical with Caraka of the *Saṃhitā*.[f] Again Dhanvantari is a legendary, divine personage in many Vedic texts of widely different ages; Suśruta is said to be the son of the Vedic sage, Viśvāmitra, but another Suśruta is referred to by Kātyāyana (a contemporary of Candragupta Maurya), the author of a *vārtika* to Pāṇini's *Vyākaraṇa*; Nāgārjuna is the name or title of at least two, possibly three, philosophers, alchemists and scholars between the third century B.C. and al-Bīrūnī's time, tenth century A.D. The difficult task of identifying the medical authors has to be undertaken only on the basis of available evidence and chance references in other sources of established chronology. The most commonly accepted dates for the composition of the *Caraka Saṃhitā* (which formed the basis of Dṛḍhabala's version) and Nāgārjuna's redaction of the older *Suśruta Saṃhitā* are A.D. 100, and third to fourth century A.D. respectively. These conclusions were arrived at by the Chronology Committee of the National Institute of Sciences of India after considering the

[a] *CS. Sū.*, 2.
[b] *SS. Sū.*, 1. 1.
[c] *CS. Sū.*, 1. 9.
[d] *Taitt. S.*, vi. 4. 9.
[e] Levi, pp. 444–84.
[f] Sen, Gananath (1), p. 11.

entire available data on the subject. The original *Agniveśa* and *Suśruta Saṃhitās* must have preceded these works by many centuries, as they had to be extensively revised and restored.

THE CONTENTS OF THE ĀYURVEDIC *SAṂHITĀS*

The *Caraka* and *Suśruta Saṃhitās* mention the eight different branches of medical knowledge,[a] but the treatises are not written accordingly. The former is an exhaustive work on the first branch (therapeutic medicine) only, though it contains many sections dealing with surgery and the other six branches. It deals mainly with anatomy, physiology, aetiology and prognosis, pathology, treatment, objectives, influence of environmental factors, medicines and appliances, and procedure and sequence of medication. For discussion of these topics the work is divided into eight *sthānas* (sections) containing 150 chapters in all. The *Suśruta Saṃhitā* follows more or less the same pattern, but it gives surgery the place of honour. In fact, the Dhanvantari school of medicine, to which it belongs, believes surgery to be the most ancient and most efficacious of the eight branches of medical knowledge.[b] The *Suśruta Saṃhitā* contains six *sthānas* dealing with fundamental postulates, pathology, embryology and anatomy, therapeutic and surgical treatment, toxicology, and a final section on subsequently gained and specialized knowledge of topics dealt with in earlier sections, and contains a total of 184 chapters. In both the works the topics are not distributed in the text in the way that would appear logical to modern minds, and often the same topic recurs in different isolated chapters. Still, the over-all picture is of codified, scientific treatises, the *Suśruta* being more concise in language and a repository of more factual information; it describes the necessity and *modus operandi* of dissections on human cadavers for gaining accurate anatomical knowledge.

The special physiological and pathological ideas of *Āyurveda* as also its special methods of a diagnosis and treatment will be discussed later. Some of its achievements merit special mention. The *materia medica* is extensive and represents a full utilization of environmental resources. More than 600 drugs of animal, plant and mineral origin are used in the *Caraka* and about 650 in the *Suśruta Saṃhitā*. The large variety of medicinal prescriptions, methods of compounding, therapeutic methods including psychiatric processes and surgical processes employing specific instruments for each type of operation are scientific, sound and exhaustive. Suśruta describes more than 300 different operations employing 42 different surgical processes and 121 different types of instruments. Some irrational methods are, however, prescribed for some mental aberrations and diseases of new-born infants.

Symptoms are described for a large number of pathological conditions and diseases, including *diabetes mellitus*, pulmonary tuberculosis, malignant

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[a] *CS. Sū.*, 30, 28. [b] *SS. Sū.*, 1.

growths, leprosy, gangrene, erysipelas, jaundice, diphtheria, tetanus, calculi, general paralysis, insanity, epilepsy, epidemic diseases, bites of poisonous snakes and animals, and hydrophobia. Rational and apparently efficacious surgery is described for many conditions including complicated fractures and dislocations, piles, fistulas and sinuses,[a] tumours, carbuncles and malignant growths, cataracts and complicated opthalmic operations,[b] strangulated hernia,[c] urinary stones causing uraemia, impacted gall-stone, intestinal perforations and protrusions of the viscera due to accidental injuries,[d] amputation of major limbs, tonsilitis, bone abscesses and abscesses of internal organs, serious head injuries with exudation of brain matter, major obstetric operations including removal of the foetus by craniotomic and other methods,[e] and congenital malformations of the nose, ears or lips.[f] The last-named operation required plastic surgery involving grafting of skin and muscular tissues from surrounding areas and other parts of the body and was also used to help people whose noses or ears had been removed for penal reasons, apparently a common practice of the period.

Apart from the above achievements, *Āyurveda* is remarkable for its special conceptions and theories. It must be emphasized that the curing of diseased conditions and the maintenance of health are not the only aims of *Āyurveda.* It is also concerned with harmonizing secular conduct and spiritual pursuit through a realization of the true relationship between the complex of body, mind and soul and the eternal universe. As such, it is more a comprehensive philosophy of life, with salvation as its goal, than a science in the modern sense of the term. Theories of creation of life, of biological processes, of sensory and intellectual perceptions,[g] genetic and eugenic rules, and the physiological and pathological effects of heredity and gestation,[h] theories of digestion, metabolism, circulation of body fluids and functions of bodily eliminations[i] and the all-embracing theory of the three omnipresent humours responsible for the origin and prognosis of all pathological conditions and forming the very basis of Āyurvedic treatment—all are found in the medical *saṃhitās.* There is a rigorous standard for the training of physicians, and a meticulous code of personal ethics and social conduct for the medical profession.[j] In insight, farsightedness and depth, the Āyurvedic medical code stands a favourable comparison with the Hippocratic code. The entire texts of the *saṃhitās* are also distinguished by careful and penetrating observations, exhaustive and classified information, and an able presentation of the available knowledge in medicine and allied subjects like chemistry, botany, etc., contributing to medicine.

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[a] *SS. Ci.*, **3, 7, 8.**
[b] *SS. Ci.*, **3, 8, 17.** 12; *Uttara*, **3, 7, 8.**
[c] *SS. Ci.*, **19.** 9–12.
[d] *SS. Ci.*, **2.**
[e] *SS. Ci.*, **15.**
[f] *SS. Sū.*, **16.**
[g] *CS. Śā.*, **5.**
[h] *CS. Śā.*, **3**; *SS. Śā.*, **1–3.**
[i] *CS. Ci.*, **15**; *CS. Vi.* **6**; *CS. Sū.*, **28**; *SS. Sū.*, **14, 35.**
[j] *CS. Vi.*, **8**; *CS. Sū.*, **9, 10, 29, 30**; *SS. Sū.*, **2, 5, 7, 10, 25, 34.**

LOST TREATISES OF *ĀYURVEDA*

Apart from the two great *saṃhitās*, there were many other treatises on the therapeutic branch of medicine, termed the Ātreya school of medicine. Some of them are lost beyond all possible hope of recovery, but their names and subjects are available from references in existing works. Such lost treatises include the *saṃhitās* credited to Agniveśa, Kṣarapāṇi, Jatukarṇa, Parāśara, Hārīta, Kṣaranāda, Viśvāmitra, Kapila and Gautama. Of the Dhanvantari school with its stress on surgery, the lost works are the *Vṛddha Suśruta* or *Sauśruta tantra*, the treatises credited to Aupadhenava, Aurabhra, Pauṣkalāvata, Gopurarakṣita, Vaitaraṇa and Bhoja. The *Bhoja-saṃhitā*, also known as *Vṛddhabhoja*, should not be confused with a lexicon compiled by Bhojarāja of a much later age.

EXTANT CLASSICAL WORKS ON *ĀYURVEDA*

Among the major existing works of the Ātreya school (apart from the Caraka) are about 50 known commentaries and editions of the Agniveśa of *Caraka Saṃhitā*,[a] the notable works being those of Dṛḍhabala (ninth century), Cakrapāṇidatta (eleventh century) and Śivadāsa (eleventh century). Among a smaller number of editions and commentaries of *Suśruta Saṃhitā*, the most notable are those of Nāgārjuna (third to fourth century), Ḍalhanācārya (tenth-eleventh century) and Cakradatta (eleventh century).

Next in importance as well as in age (with the possible exception of *Kāśyapa Saṃhitā*) come two works with somewhat similar names, the *Aṣṭāṅga Saṃgraha* also known as *Vṛddha Vāgbhaṭa* and the *Aṣṭāṅgahṛdaya*, known simply as *Vāgbhaṭa*. Both are comprehensive works on therapeutics and surgery, one in prose-*cum*-verse and the other in verse alone. From the distinctive name of the first work as the 'ancient' Vāgbhaṭa, some assumed differences in quality, and from the very fact of the existence of two different works, it has been supposed that there were two different authors of this name, one earlier and one later. The authors (or author) in both cases, however, claim the same parentage and profess the same school of Buddhist faith. It is known that Vāgbhaṭa was the son of Siṃhagupta, an inhabitant of Sind and a disciple of Avalokita, the Buddhist sage, but no separate particulars are available about the other author. The internal evidence also shows an identity of style, medical views and mode of presentation, and there is no real evidence to show that there was more than one author of this name.[b]

The first mention of a medical book on *Aṣṭāṅga* is found in the memoirs of the Chinese traveller I'Tsing of the seventh century. The author of this book has been identified with the Buddhist Vāgbhaṭa who may, therefore, be placed in the seventh century A.D. or a little earlier.

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[a] Rây and Gupta, p. 1.

[b] Sen, Gananath (2), p. 51.

The *Aṣṭāṅgahṛdaya* is by far the most concise and scientific exposition of Āyurvedic knowledge, incorporating the teachings of the Ātreya, Dhanvantari and Rasāyana[a] schools of medicine and distinguished by its knowledge of chemical reactions and laboratory processes. The work has been translated into many Indian and foreign languages, and enjoys a deserved reputation rivalling those of Caraka and Suśruta. The important commentaries on Vāgbhaṭa's works are by Aruṇadatta (thirteenth century), Candrānanda, Hemādri and Indu.

The *Kāśyapa Saṃhitā* is another ancient treatise dealing mainly with paediatrics. It is probably of an age not much later than that of the *Bhela Saṃhitā*, if we consider that it is admittedly an abridged edition or version of an earlier work, the *Vṛddha Kāśyapa*.[b] It is quoted in the Bower manuscript and contains many quotations, not found elsewhere, from the most ancient works of the Ātreya school including some missing treatises.

A valuable work, specializing on the diagnostic aspect of medical knowledge, is due to Mādhavakara (eighth or ninth century) and is entitled *Rugviniścaya* or *Mādhava Nidāna*. It is a compilation from the earlier works of Agniveśa, Suśruta and Vāgbhaṭa, but its merit lies in its scientific selection of knowledge included, concise presentation, and as a valuable clinical guide. It is famous all over India as the best Āyurvedic work on diagnosis of diseases. Two commentaries on this work, *Madhukoṣa* by Vijayarakṣita and *Ātaṅkadarpaṇa* by Vācaspati, are also valuable aids to diagnosis. The *Gadanigraha*, a medical treatise by Ṣoḍhala (seventh century), *Ṣoḍhalanighaṇṭu*, a medical lexicon by the same author, *Siddhayoga* by Vṛndakuṇḍa (ninth century), and *Cakrasaṃgraha*, a valuable treatise containing quotations from earlier works by Cakrapāṇidatta (about A.D. 1050), are other important works on the Ātreya and Dhanvantari schools, containing also some information on inorganic medicines, written before A.D. 1200. Only a few of the Āyurvedic works listed above are available in printed editions, others being in the form of written manuscripts preserved in various collections in India and abroad. The descriptions and locations are to be found in Aufrecht's Catalogue. Kavirāj Gananath Sen has made an assessment of the comparative merits of these different works.[c]

ĀYURVEDA AND ITS EIGHT CLASSICAL DIVISIONS: OTHER MEDICAL SYSTEMS OF ANCIENT INDIA

THE EIGHT *AṄGAS* OF *ĀYURVEDA*

The term *aṣṭāṅga* (eight-limbed) used in the titles of Vāgbhaṭa's works is actually a synonym of *Āyurveda* which, from ancient times, has been supposed to contain eight branches of medical knowledge. These branches

[a] Keith (3), p. 510.
[b] Subba Reddy, pp. 1–35.
[c] Sen, Gananath (1), pp. 5 ff.; (2), pp. 32 ff.

are enumerated in the introductory passages of all important Āyurvedic works though most of them specialize in one or at most two branches and give only limited space to the rest. The lists given by Caraka, Suśruta and Vāgbhaṭa are identical though different in order.[a] Caraka uses the term *viṣagaravairodhikapraśamana* for antidotes and cures for poisons and venoms in place of *agada* (toxicology). The eight branches and the topics they include are enumerated below:

(i) *Kāyacikitsā* (therapeutics) dealing with the aetiology, diagnosis, prognosis, treatment and recommended diets in fevers, gastro-intestinal irritations, coughs, consumptive maladies, urinary complaints and other ailments, curable by the administration of drugs, externally or internally;

(ii) *Śalyatantra* (surgical knowledge) divided into two branches; the first deals with diagnosis, prognosis and treatment of conditions amenable to surgical methods, specifications and uses of different surgical instruments, methods of bleeding, cauterization by heat and alkali, use of leeches, and minor surgical implements in appropriate contexts; the second deals with surgical knowledge applied to gynaecology and obstetrics;

(iii) *Śālakyatantra* (treatment of diseases of the eyes, ears, nose, tongue, oral cavity and throat);

(iv) *Bhūtavidyā* (knowledge of mental diseases and diseases of supernatural origin) dealing with the true nature, symptoms and treatments of conditions like insanity, epilepsy, etc., in which people behave as if affected by demons;

(v) *Kaumārabhṛtya* (knowledge of infantile disorders, care of young children and treatment of diseases specific to children);

(vi) *Agadatantra* (toxicology) dealing with symptoms caused by accidental or intentional administration of mineral, vegetable and animal poisons, bites by venomous snakes and other poisonous creatures, their immediate antidotes and methods of treatment;

(vii) *Rasāyana* (knowledge of tonics and processes for arresting the process of physical and mental decay) dealing with potent drugs and prescriptions to combat ill health, natural decay and senility, their dosages and methods of administration;

(viii) *Vājīkaraṇatantra* (knowledge of virilifics) dealing with lost or diminished virility, potency and procreative ability.

THE ĀTREYA AND DHANVANTARI SYSTEMS

The medical literature specializing in the therapeutic and surgical branches of medical knowledge has already been reviewed in the previous section. Most of the works mentioned there however claim to be a

[a] *CS. Sū.*, 30; *SS. Sū.*, 1.

comprehensive treatise on *Āyurveda* (and hence on all its branches) and generally devote some passages or even sections to the other six branches.

Quite a number of treatises specializing in the other *aṅgas* were also in parallel existence with the works of the Ātreya and Dhanvantari schools. But the zeal displayed by later scholars for reproducing or editing the latter works seems to have been lacking for the other branches. Original works in the other *aṅgas* are generally met with only in the form of quotations in later works or in names only; commentaries and revised editions are conspicuous by their absence. Even the quotations that are found are few and far between. A study of the literature of *Āyurveda* in the post-Vedic period leaves a strong impression that the works of the Ātreya and Dhanvantari schools were always considered the elite among medical treatises while the others were considered second-class matter.

THE *ŚĀLAKYATANTRA* SYSTEM

A class of physicians known as *Śālākis* specialized in this branch of medicine, the chief treatise of which was *Videhatantra* supposed to be the work of King Janaka of Videha. This work is mentioned as important in the sections on *Śālakyatantra* found in the *Suśruta Saṃhitā*,[a] and has been extensively quoted by Ḍalhaṇācārya, Vijayarakṣita Śrīkaṇṭhadatta and others. Other works on this branch of medicine, quoted by the last three authors, are *Nimitantra* and *Sātyakītantra*. Caraka mentions the *Kāṅkayanatantra* and the *Śaunakatantra*. Ḍalhaṇa and Śrīkaṇṭha also mention other works in this branch, attributed to Gārgya, Gālavya, Karālabhaṭṭa, Kṛṣṇātreya, as also another work *Cakṣuṣyatantra* dealing with eye diseases alone. None of these works are available now but all must have been extant in Ḍalhaṇa's time (tenth-eleventh century). The sparse quotations available do not permit of a proper assessment of these works.

BHŪTAVIDYĀ

No special treatise on this subject has been quoted or even named in the surviving works. This branch of *Āyurveda* survives now only as chapters in the works of Caraka,[b] Suśruta[c] and Vāgbhaṭa.[d] The *Caraka Saṃhitā* treats all psychic maladies, including grave diseases of the nervous system, insanity and demoniac possessions, in a single chapter. The *Aṣṭāṅga* and *Suśruta Saṃhitā* consider demoniac possessions as separate from mental diseases. The *Agnipurāṇa* and the *Vāyupurāṇa* also deal with demoniac possessions and the remedial measures recommended for them. From the fact of Caraka's classification of demoniac possessions in the same chapter

[a] *SS. Sū.*, 24; *SS. Ci.*, 22.
[b] *CS. Ci.*, 9.
[c] *SS. Uttara*, 39–62.
[d] *Āṣṭ. Hṛ Uttara*, 4 and 5.

with mental disorders and Suśruta's declaration that malignant spirits cause diseases but do not physically 'possess' human beings (*na te manuṣyaiḥ saha saṃviśanti*), it seems likely that in these times *bhūtavidyā* simply meant psychic disorders caused by unknown forces. The later treatises after Vāgbhaṭa ignore this branch of medicine altogether, possibly to avoid being branded with the stigma of superstition.

THE *KAUMĀRABHṚTYA* SYSTEM

The *Kāśyapa Saṃhitā*, as is to be expected, contains considerable information on infantile disorders and care of new-born babies and older children. The *Uttaratantra* of Nāgārjuna's version of the *Suśruta Saṃhitā* devotes no less than 12 chapters to this branch of medicine. Invocation of divine blessings, chanting of holy words and propitiation of supernatural forces formed a major part of such treatment, along with treatment by therapeutic drugs. The chapters in the *Suśruta Saṃhitā* convey the clear impression that an extremely high value was put on the health, welfare and mental happiness of children at this time. This started even from the period of conception, and an equally high value was placed on the physical and psychological well-being of expectant mothers. Midwifery and gynaecological knowledge was not, however, included in the branch of *Kaumārabhṛtya*.

The treatises known to have dealt specially with this subject were the *Jīvaka tantra* quoted in Cakradatta's commentary *Bhānumatī* on the *Suśruta Saṃhitā*, *Pārvataka tantra*, *Vandhaka tantra* and *Hiraṇyākṣa tantra* (quoted by Śrīkaṇṭha Datta). These works survive only in names, except for occasional quotations.

THE *AGADATANTRA* SYSTEM

The *Caraka Saṃhitā* devotes only one chapter to this branch of medicine but the *Suśruta* has one of its six *sthānas*, e.g. *Kalpasthāna*, entirely on toxicology. Apart from symptoms, first-aid measures and long-term treatments, there is a very good classification of different poisons and on different methods by which unwary persons may be slowly or quickly poisoned. The detection of some inorganic poisons by flame tests is a remarkable feature. There is also an exhaustive classification and description of different types of poisonous snakes and the symptoms of their bites. Similar information (including a faithful account of the symptoms of hydrophobia) is found for poisonous insects, aquatic and amphibious creatures and land animals. In fact, the *Kalpasthāna* of the *Suśruta Saṃhitā* is a valuable treatise on toxicology by its own right.

A treatise on toxicology, also named *Kāśyapa Saṃhitā*, written in Sanskrit but printed in local script, is found in South India. Some passages in this work are identical with certain quotations in the works of Ḍalhaṇa,

Cakrapāṇi and Śrīkaṇṭha.[a] But the authenticity of the text cannot be verified. Śrīkaṇṭha also gives quotations from another work in this field, the *Avalamvayanasaṃhitā*, which must have survived up to the seventeenth century but is now untraceable. Another treatise on *agadatantra*, the *Sanaka Saṃhitā* (or *Śaunaka Saṃhitā*), survives in an Arabic translation discovered by Max Müller.[b] Ḍalhaṇa quotes from another treatise on this subject, apparently his own work, in his commentary on Nāgārjuna's *Suśruta Saṃhitā*.

In Cochin and Travancore, many other Sanskrit works on *agadatantra* are available in the local script. Their authenticity and antiquity have not been established beyond doubt.

THE *RASĀYANA* SYSTEM

The conception of *rasāyana* (restorative treatment) is a notable feature of *Āyurveda*. With age there is a degeneration of bodily tissues, sensory perceptions, as also of physical and intellectual vigour. *Āyurveda* considers this process not only preventible but even reversible and does not consider senility an inseparable condition of old age. This branch of medicine employs some remarkable processes, as well as herbal, mineral and metallic substances as tonics. Here also most of the specialized works are unavailable, but a fair knowledge of the methods and drugs are obtained from the sections devoted to *rasāyana* in the works of Caraka, Suśruta and Vāgbhaṭa. Mercurial and other inorganic preparations of the *Rasacikitsā* school of medicine (*vide* later) found in Tantric works were also credited with similar rejuvenating powers.

Suśruta extols the virtues of clean living, high thinking, proper physiological habits and regular exercise, regular use of milk, pure cold water, honey, clarified butter, various special diets including salt-free diets, preparations containing gold and minerals, and various prescriptions of recommended drugs for *rasāyana*.[c] The mythical *soma* plant (yet to be identified with any known plant), used with auxiliary tonics and a strict regimen of diet and conduct, is said to bring about complete rejuvenation in body and mind, ensuring a fresh lease of youth.[d]

The lost texts on this subject include *Śodhanatantra* quoted in the *Cakrasaṃgraha* of Cakrapāṇidatta, the works attributed to Vyādi, Vaśiṣṭha and Māṇḍavya (quoted in *Rasaratnākara* and *Rasaratnasamuccaya* and *Nāgārjunatantra*). The last-mentioned work is by one of the many medical scholars in successive ages with the title of 'Nāgārjuna'.

THE *VĀJĪKARAYA* SYSTEM

This branch of medicine is not dealt at any length in any of the medical works after *Caraka* and *Suśruta*, where they are found in

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[a] Sen, Gananatha (2), p. 43. [b] Rây (P. C.), p. lxv. [c] *SS. Ci.*, 27–29. [d] *SS. Ci.*, 29.

fragmentary passages.[a] There is, however, unmistakable evidence of a considerable literature on this subject, current in the early Buddhist period. The famous *Kāmasūtra* of Vātsyāyana gives the names of three works on this branch of medical knowledge, including the *Kucumāra tantra*, which is said to be an exhaustive work, already ancient at the time (*c.* A.D. 300).

The justification of including formulae of virilific tonics in a work of medicine is found in *Caraka*,[b] where it is stated that the final metabolic product of all nutritive food is the seminal fluid, and the loss of the latter is the most serious drain possible on the body's vitality, so that all sexual excesses lead to serious wasting diseases and even death unless counteracted by *rasāyana* remedies.

THE *RASACIKITSĀ* SCHOOL OF MEDICINE

Apart from the eight classical branches of *Āyurveda*, some other indigenous systems have survived as integral parts of the medical knowledge of ancient India. Some of the obscure pre-Aryan concepts and practices have been noted earlier. The quasi-religious system of *Rasacikitsā* has a reputation second only to *Āyurveda.* With a few exceptions this school employs only metals, alloys, metallic compounds and salts and also sulphur and its preparations in its *materia medica.* According to it, quicksilver is the foremost among all medicinal substances. This latter belief is found also in many Buddhist and Brāhmaṇic tantras, as a part of the Tantric faith.[c] The medical knowledge of India exported to Tibet, China, Indo-China and Ceylon contained much of this school of medicine mixed with classical *Āyurveda.*

The early practitioners of this school were known as *Siddhas* who introduced many of the metallic preparations which were either unknown to, or not utilized in, classical Āyurvedic practice. The Tamil *Sittar* works on medicine, chemistry and allied subjects were possibly originated by the *Siddhas.* The first use of mercurial compounds in medicine is found in *Suśruta* (third-fourth century);[d] here the modern and surviving name of mercury, *pārada*, is used; the more ancient synonym, *sutāraḥ*, is found in the *Suśruta Saṃhita*,[e] but its omnipotence in all diseases and indeed in all phases of life was first propounded in Tantric texts written by the early *Siddhas.* The alchemical preparation of gold (which also was believed to be an embodiment of perfection and therefore a panacea for all ills) from mercury was another aim of this school and many supposed processes to this end are found. The classical work of Mādhavācārya (fourteenth century),[f] describing the sixteen schools of belief current in his time, gives a description of the *Raseśvaradarśaṇa* (faith in divine mercury), in which the metal is believed to be the earthly embodiment of the omnipotent deity,

[a] *CS. Ci.*, 2; *SS. Ci.*, 26.
[b] *CS. Ci.*, 2.
[c] Ray (P. C.), p. xxxv.
[d] *SS. Ci.*, 25. 20.
[e] *SS. Ka.*, 2, 12.
[f] *Sarvadarśanasaṃgraha*, pp. 137–44.

Śiva, and as such to be worshipped. The use of mercurial preparations was also believed not only to give perfect health and cure of all diseases, but also prosperity, a perfect mind, bliss and eventual salvation.

The works of the Tantric period, devoted to the preparation of inorganic and metallic remedies, are among the most prolific and rewarding sources of the knowledge of Hindu chemistry. These works were, however, primarily concerned with rituals, alchemy and chemical processes. Their value as medical literature lies chiefly in their exposition of the medical philosophy of this school, their iatrochemical ideas and practices, and the inorganic remedies they contributed to medicine. The most important among them are: *Rasaratnākara* and *Ārogyamañjarī* of Siddha Nāgārjuna (seventh century), *Siddhayoga* of Vṛndakuṇḍa (seventh-eighth century), the *Cakrasaṃgraha* and the commentaries by *Cakrapāṇidatta* (eleventh century), *Rasahṛdaya* of Govinda Vāgbhaṭa (eleventh century), *Rasaratnākara* of Siddha Nityanātha, *Rasaratnasamuccaya* of Vāgbhaṭa (a namesake, living in the late twelfth century), *Rasārṇava* by Śambhu (twelfth century), *Rasendracintāmaṇi* by Rāmacandra (twelfth century) and *Rasendracūḍāmaṇi* by Somadeva (twelfth century). These works are available in most first-class collections of Āyurvedic literature in India and abroad. Many of them were edited and published during the last century, notably by the Āyurvedic Granthaśālā of Bombay.

The *Rasacikitsā* school of medicine has been a rival of *Āyurveda* in popularity and prestige during many centuries in the past, specially in South India, the eastern provinces and Sind. It survives to the present day as a living system of medicine, but has largely discarded its deification of mercury and has absorbed many tenets of classical *Āyurveda*. The Kavirājas, that is medical practitioners who follow the Āyurvedic system of medicine in their treatment, possibly rely more on inorganic remedies than on the *materia medica* of classical *Āyurveda*. This preference can be explained by the greater facility in manipulation during compounding, greater portability and easier storage, easier preservation and less wastage, and simplicity of prescription and dosages of inorganic remedies.

THE *NĀḌĪVIJÑĀNA* SYSTEM OF DIAGNOSIS

The other quasi-Āyurvedic system of importance is termed *Nāḍīvijñāna* and, as the term implies, attaches great importance to the pulse felt at the wrists, a close study of which is supposed to give sufficient indications for the diagnosis of most diseases. The term *nāḍī* in *Āyurveda* means not only the arteries and veins but all major and minor tubes as well as nerves, etc., in the body; *nāḍī* does not mean the pulse in *Āyurveda*. Moreover, the very spirit of *Āyurveda* is opposed to the idea of putting complete reliance for diagnosis on the unaided touch perception of the physician. The earlier medical treatises recommended that while making a diagnosis all known factors should be taken into consideration and all the senses of the

physician should be employed.[a] The main thesis of *Nāḍīvijñāna*, that diagnosis is possible and death predictable by feeling the pulse beats, implies that the condition of the heart indicates all diseased conditions, an idea open to doubt. On the other hand, it is quite possible that the acute perception of a highly trained person could discern the condition of the three *doṣas* (fundamental humours) in the body which, even according to *Āyurveda*, is the basic factor in the causation, prognosis and treatment of all diseases. Acute perception may also predict the failure of the heart and set a period to the termination of its functioning. The claim of ability to foretell death by *nāḍīvijñāna* need not be ruled out. It must also be pointed out that the school of *nāḍīvijñāna* does not forbid the consideration of other symptoms or the case history in arriving at a diagnosis; they are only considered much less important.

A supposedly ancient treatise of this branch of medicine, *Nāḍīparikṣā* by Rāvaṇa (a comprehensive treatise on this subject), and another work *Nāḍīvijñāna*, claiming to embody the teachings of Kaṇāda and Gautama on this science, give us an idea of this school of medicine. The styles of writing of both these works do not support any claim to antiquity and they may be comparatively recent works,[b] at least much more recent than the periods of the legendary demon-king Rāvaṇa of the *Rāmāyaṇa* (who is claimed to be the author of the first work) or even of the great philosophical teachings incorporated in the *Caraka Saṃhitā* and possibly the more ancient *Agniveśa Saṃhitā*. The classical compendiums of *Āyurveda* do not contain any clear reference to *nāḍīvijñāna*, and it is logical to suppose that this branch of medicine came into existence in much later times. The medical literature of the Tantras contains innumerable references to *nāḍī* but here the term has suffered a semantic change and generally meant nerves, which also were considered fundamental causative factors in diseases and bodily conditions.

THE YOGA SCHOOL

The Yoga system of philosophy,[c] due to Patañjali (*c.* second century B.C.), with its mental and physical discipline by the eightfold path of *yama* (abstention), *niyama* (observance), *āsana* (physical postures involving muscular co-ordination), *prāṇāyāma* (regulation of breathing), *pratyāhāra* (voluntary control of the sense-perceptions), *dhyāna* (fixed attention), *dhāraṇā* (contemplation) and *samādhi* (ultimate and absolute mental concentration), is not only a philosophy but also a discipline of the body to make it function in a state of perfect health and flexibility. A branch of this discipline, known as *haṭhayoga*, is a refined form of physical culture involving the voluntary as well as involuntary muscles of the body and claims to cure many pathological conditions. This integrated system of

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[a] *CS. Vi.*, 4; *Ni.*, 1. 13; *SS. Sū.*, 10.

[b] Sen, Gananatha (2), p. 69.

[c] Das Gupta, II. pp. 273–463.

mental concentration, breath control, sense-control and physical culture can also be called a medical system. *Āyurveda* has not borrowed from it but this system has always been held in high respect in India and has recently earned a spate of popularity in Western countries.

ĀYURVEDA: THEORIES AND CONCEPTS

DISTINCTIVE FEATURES OF ĀYURVEDIC SCIENCE

Āyurveda, as has been said earlier, is not limited to mere medical knowledge. It wants that all men should be healthy, fit in body and keen in mind and that they should maintain this state as long as possible; the ultimate ends being mundane happiness and spiritual elevation. To achieve these objectives *Āyurveda* developed into a comprehensive encyclopaedia of knowledge in medical subjects like genetics, gynaecology, obstetrics, aetiology, diagnosis, therapeutics, surgery, physiology, biology, diet, ethics, personal hygiene, preventive treatment and social medicine; allied subjects like animal biology, botany, cultivation, pharmacognosy, compounding and chemistry; and some subjects, not usually considered as medical, like cosmology, climatology, psychology, parapsychology, philosophy and religion. Mastery of *Āyurveda* presupposes knowledge in all these fields.

Not only are the objectives and scope of *Āyurveda* more extensive than those of formal medical science; this Indian science is also distinguished by some fundamental theories and postulates which pervade all its precepts and practices, but which are not found in modern medicine. These theories and concepts are, however, not all archaic or even empirical; many are based on observations and metaphysical reasonings. These special theories and concepts of *Āyurveda* merit examination even if their correctness is open to question.

COSMIC ORIGIN OF MATTER AND LIFE

According to *Āyurveda*, matter, energy, sentience, life, intelligence and motility, all result from synthesis of ingredients evolved out of cosmic forces. But this synthesis is neither a matter of accident or chance nor the result of a slow and gradual evolution through the stages of inanimate matter, lower forms and less intelligent species. Every time a new life comes into existence inside a microscopic speck of fertilized matter, the mind, senses and potentiality of growth are created anew out of the fundamental components present in *prakṛti* (the ultimate ground) under the subtle influence of a momentary union with the *puruṣa* (the absolute self-conscious principle). *Prakṛti* which is the only source of all things which are perceptible to the senses or discernible to the mind has eight aspects

and 16 mutations, all devoid of *cetanā* (awareness). The eight aspects are: *avyakta* (the unmanifested, ultimate ground), *mahān* (ultimate experience), the three fundamental reals (*sattva*, *rajas* and *tamas*) and the three *ahaṃkāras* (egos) of guidance, energy and inertia. The 16 mutations are the five organs of perception, five organs of action, the *mind* and the five *tanmātras* (subtile essence of matter and manifestations). Consciousness and hence life in a living organism are the contribution of the *kṣetrajña* (eternal, indestructible and ubiquitous soul) which, at the moment of conception, voluntarily enters into a divine, human or subhuman plane of existence inside a material body as *karmapuruṣa* until death separates it.[a]

The eternal mother-principle, *prakṛti*, out of which all living organisms are created and gain sustenance possesses three aspects; the fundamental *guṇas*, or reals, of *sattva* (tendency to manifestation, essence of intelligence stuff), *rajas* (essence of energy) and *tamas* (material existence, universal inertia). These aspects of the Ultimate Ground have the inherent potentialities of evolving into varied forms of natural phenomenon, matter, and animate intelligent life through innumerable permutations and combinations of the 16 mutations. The three reals are first mutated into the three forms of *ahaṃkāra* (ego)—spiritual ego of guidance and transformation, the subjective ego of energy and motion and the objective ego of mass and inertia. The first ego combining with the second creates the five organs of sense-perception (vision, hearing, smell, taste and touch), the five operative organs (speech, locomotion, manipulation, reproduction and evacuation), and also the mind which is the versatile organ. The third ego combining with the second creates the five *tanmātras* (subtile particles with the potentialities of materialization and perception) which are the originators of the five material elements (earth or solid, water or liquid, air or gas, fire or energy, and ether or space) and also of the perceptible phenomena of vision, sound, smell, taste and touch. Thus every living being is a complex aggregate in which a *karmapuruṣa* remains united with a material body, mind, sense organs and motile organs, contributed by and sustained by the 24 *tattvas* or *prakṛti*.[b]

Hence all living organisms have a soul associated with it, a mind composed of the three reals, ten organs evolved out of the three egos (three humours which are the counterparts of the cosmic principles of air, dry heat and moisture) and a material body composed of the five gross elements present in the form of *kalās* (protective layers), *dhātus* (component matters like blood, body fluids, tissues, bones, etc.), *malas* (eliminations and excretions), all functioning by the bodily counterparts of natural phenomena in the shapes of the three *doṣas* (humours), *agni* (digestive fire) and *kriyās* (natural activities like sleep, respirations, pulsations, elimination, metabolic processes, etc.).[c] Inasmuch as the fundamental components and primary elements constitute the living organism, each contributes its specific nature and properties to the individual in the proportion in which it is present.

[a] *CS. Śa.*, 1. [b] *SS. Śa.*, 1. [c] *SS. Śa.*, 1; *SS. Uttara*, 64, 2–3.

THE COMMON CONSTITUENTS OF ALL LIVING AND NON-LIVING MATTER

The *pañcabhūtas* (five elementary principles of earth, water, fire, air and space) which constitute all material substances have different properties and characteristics. The earth principle gives mass, hardness, compactness, roughness, inertia, density, opacity, smell, and tactile sensations; the water principle gives fluidity, viscosity, coldness, softness, unctuousness, and taste; the energy principle gives visibility to objects, colours, periodicity of motion (*santāna*), digestion, anger, instantaneous response, courage, and the visual sensation; the air principle gives perception by physical contact, all physical and physiological movements, pulsations, sense of lightness and the tactile sense; the ethereal or space-principle gives sound, porosity, bodily cavities, functional subdivisions of the bodily channels and tissues into finer and finer branches, and the sense of hearing.[a] From these arise the infinite diversity of matter, some of which are predominantly composed of one element and some of two, three or more, with corresponding complex properties. Organic matter and the components of living substances (and plants) are generally composed of all the five elements in different proportions and possess combinations and resultants of all the material and physiological properties listed above.

Living organisms also possess such resultant properties and characteristics. The sense perceptions corresponding to the five elements also enter into their make-up through the agency of the sense-organs, as also the motor activities of locomotion, manipulation, speech, reproduction and evacuation. All these components and attributes remain in a state of equilibrium and balanced existence, complementing the functions of each other. But the infinite number of possible combinations makes a 'perfect' organism a near impossibility. Hence health is only a state of optimum balance. The greater the approximation to the ideal state, the better the health; diseases and pathological conditions are due to imbalances and deficiencies of the components. These characterisitc properties, functions and deficiencies collectively constitute a living organism.[b]

Apart from these general attributes of non-living and living matter, there are certain mental components which are the special (but not exclusive) attributes of man. These are the emotions of pleasure and pain, voluntary movements, mental perception, will, logical faculty, memory, knowledge gained by experience and creative thinking. But even among men there are different combinations of the three reals constituting the mind, giving rise to widely different mental levels, different personalities, different abilities, instincts and behaviour.[c]

THE THEORY OF THE MICROCOSM AND OTHER PHILOSOPHICAL CONCEPTS

There is a remarkable theory in *Āyurveda* to the effect that man is an epitome of the universe, a 'microcosm' of the macrocosm. Both the universe

[a] *SS. Śa.* 1. 20–21. [b] *SS. Śū.*, 15; *SS. Śa.*, 1 and 2. [c] *SS. Śa.*, 1. 18–19.

and man are manifestations of one and the same eternal spirit. Spirit and matter are equally integrated in both. The material contents of both are constituted of the same five primal elements, endowing their specific and resultant characteristics to both. *Pṛthvī* confers the solid complement to both; *apas* the liquid; *tejas* (the manifestation of radiant energy) confers vision, body-heat and digestive fire to man; *vāyu* enveloping and permeating the earth, supporting combustion, helping growth and initiating movements also permeates the body as vital breath and promotes growth from the foetal stage, and causes bodily movements; *ākāśa* confers the orifices and empty spaces inside the body. Like the infinite diversity present in the universe, the different units comprising the body are too numerous to count. In the mind of man also there are as many moods as in nature. Similar to the office of the Brahman in the universe is that of the *puruṣa* in man; both can create life by the act of impregnation, both are unlimited in might and potentiality; the true nature of both are unknown and unknowable.[a]

The concept of the 'microcosm' follows the philosophical doctrines of the *Sāṃkhya* and *Vedānta* schools of Indian thought. The theories of cosmic evolution of matter and life and of the common constituents of living and non-living matter (recounted earlier) are also based on *Sāṃkhya* and *Nyāya-Vaiśeṣika* doctrines. The idea of the eternal and omnipotent soul serving a span of existence inside an animated body, as a result of the residual effects of *karma* (deeds in previous births), is from the *Nyāya.* The properties of the five primal elements and the physiological actions of the different taste-matters (*vide* later) are also found with variations in many schools of Indian philosophy. The basic common concepts of Indian philosophy have also been largely incorporated into *Āyurveda.* *Āyurveda* accepts that the highest aim of life is the quest for ultimate truth and realization; that the perception of our senses is not valid in the absence of spiritual insight; that suffering is due to the human error of discrimination between the body and mind which suffer and the spirit which is immune; that the final wisdom is to shed passions and illusions; that the supreme essence of power and awareness is present in man, making him potentially omniscient and omnipotent when he achieves self-realization; and that it is possible for the trained mind to achieve this self-realization and salvation; a healthy body, long life and a keen mind being desirable aids to this end. These ideas are not mere abstract exercises in philosophy; they have far-reaching social, personal and medical consequences and explain the insistence in *Āyurveda* on self-discipline in all spheres of life, medical care and hygienic rules to keep the mind and body at the highest pitch and in perfect long life.

GENETICS AND EMBRYOLOGY

The *puruṣa* is infinite in number, each a disembodied soul capable of penetrating anywhere in space. When such a soul enters into the complex

[a] *CS. Śā.*, 5.

of sperm and ovum, formed by the act of mating, it immediately endows the impregnated matter with its own attributes of consciousness, perception, creative ability, volitional movement and the faculties of observation, knowledge, self-expression and self-maintenance. The three *guṇas* also are imparted by the *karmapuruṣa*, though in varying proportions, so that men differ in character and ability. But the *puruṣa*, transformed into the individual *karmapuruṣa*, remains unchanged in essence, because it is eternal and immutable.[a]

This life, as we understand it, commences at the moment when the minute particle of fertilized ovum gains the above attributes. This particle is immediately propelled by *vāyu* into the uterus to stay there until it is again propelled out of the mother's body by *vāyu* at the time of temporal birth.[b]

If the *kṣetrajña* does not by its own volition enter into the zygote, no life is created and conception fails to occur. Hence the process of fertilization by the act of mating is not sufficient for the creation of life, though a necessary precondition, and creation of life is not possible by unaided human endeavour. The intervention of the unknowable soul is necessary. This soul creates its own body by gathering to itself the elements, first the *ākāśa* and then the others in due order; but in this and subsequent acts in the life span, the *karmapuruṣa* is subject to certain limitations due to the residual effects of *karma* of previous births.[c]

Creation of life is possible only by the combined contributions of the *kṣetrajña* and the parents who contribute their *bījas* (sperm and ovum) containing the essence of their mental and bodily constituents (as existing at the time) in infinitely minute replicas. A human womb, therefore, invariably reproduces a human child; but temporary differences existing at different times and the resultant of the opposed male and female principles make the children differ from each other and from their parents. Such factors also explain male and female births (by dominance of the male or female *bīja*), twin and multiple births (by fragmentation of the zygote), individual characteristics, abnormalities and congenital diseases (chosen by the *karmapuruṣa* or inherited from the parents). The growth, shape, energy, vigour and sense of contentment of the future individual depend upon nourishment and environmental factors. The mental traits are determined by the quota of *guṇas* inherited from previous birth.[d]

It may be noted that this theory is in conformity with the continued identity of the germ-plasm through successive generations, though the actual individual may vary widely in mental and physical characteristics and also with the fact of continual mutations by accidents, infections and parental factors.

THE THREE HUMOURS

The humoral theory of *Āyurveda* makes a comprehensive approach to the three major branches of medical knowledge, namely physiology,

[a] *CS. Śā.*, 3 and 4.
[b] *SS. Śā.*, 3.
[c] *CS. Śā.*, 3 and 4; *SS. Śā.*, 1 and 3.
[d] *CS. Śā.*, 2 and 3.

pathology and treatment. A proper assessment of the Āyurvedic science is largely dependent upon an understanding of this unified theory, and of the significance and real nature of the three humours. The actual term used in the *Āyurveda* is *tridoṣa*. The use of 'humours' to designate *tridoṣa* should not, however, be taken to imply that *tridoṣa* means exactly what humours stand for in the case of Greek or medieval European medicine. Despite similarities of ideas and concepts, there are important differences between the *tridoṣa* concept of the *Āyurveda* and the Greek humoral theory. *Vāyu, pitta* and *kapha* are supposed to be present in all living creatures, diffused simultaneously in every minute portion of the organism, and to activate and govern the entire biological process between conception and death. The convention of equating the three humours with air, bile and phlegm (possibly following Greek ideas on the subject) is misleading to a degree. Āyurvedic ideas represent them as manifestations of universal motile, fiery and placid phenomena. The normal physiological processes represent the normal and complementary balanced manifestations of the principles in the microcosm. Individual shortcomings and congenital defects can be ascribed to their imbalance at conception, pathological conditions and diseases as causal manifestations of their temporary imbalance, paucity, excess or derangement. Hence diseases can be cured by restoring the desired equilibrium or by pacification, restitution or expulsion of the offending *doṣas*. These curative measures are possible by administering *bheṣajas* (substances having the desired potentiality of restitution, restoration or pacification) and by the processes of cleansing, evacuation or surgery.

Vāyu is self-begotten, eternal and all-pervading. Though invisible, it manifests itself by its properties of coldness, lightness, desiccating action, sound, feel, great speed, angular motion and inconceivable latent power. Its bodily manifestation courses through the organism in constant currents at high speed. If impeded in its course by any reason it becomes lodged in wrong places, generating progressively increasing pressures and getting progressively deranged. In its deranged condition it is the principal *doṣa*, because it has the greatest potentiality of causing damage. In its equable state also it is the principal humour, for it maintains the major physiological functions and movements and is responsible for maintaining a desirable equilibrium between the humours, digestive fire, metabolic products and excretions. *Pitta*, the cosmic fiery principle, is responsible for the creation in the body of heat, energy, perception to all forms of radiant energy, vitality and blood, and the maintenance of the pumping action of the heart and skin temperature. *Kapha* or *śleṣman* supplies the placid and cooling principles to the body in the processes of semen formation, growth, nutrition, taste-perception, flushing, and lubrication between hard parts. Deranged *pitta* and *kapha* give rise to specific symptoms affecting the bodily elements in their respective spheres of influence. According to different bodily locations and functions, each of the humours exists in five different forms.[a]

[a] *CS. Sū.*, **12**; *SS. Sū.*, **15**; *SS. Ni.*, **1**.

Apart from a few exceptions, all individuals have a predominance of one of the three humours and, therefore, an inherent imbalance. The few exceptions and near exceptions enjoy perfect or near-perfect health and are immune to diseases. The others are always susceptible to diseases due to the ever-present possibility of aggravating the inherent imbalances, but normally remain tolerably healthy as long as the humours are not provoked by injudicious diet, wrong conduct or environmental conditions which are at variance with their individual humoral states. For example, if a person with excess of *vāyu* indulges in foods and acts which provoke that humour, this humour is deranged and afflicts the person with mental or physical disorders peculiar to this humour. The same holds true for *pitta* and *śleṣman.* The individual types are much less affected and may, in fact, be benefited by indulging in foods and acts which provoke the other two humours. The distinctive aetiology and prognosis of different diseases are due to the large number of possible permutations and combinations of the three humours, each with five varieties, multiplicity of functions and different possible degrees of provocation. Diseases are minor, major or incurable, according to the degrees of humoral derangement. Logically, the cure lies in primarily detecting the deranged humour or humours and assessing the severity of derangement, and secondarily in identifying the specific malady by case history and symptoms. Armed with this knowledge and with the varied drugs and processes at his command, the physician can apply his knowledge of medical science to correct the specific imbalances and aggravations and ultimately effect a cure.[a]

Āyurveda recognizes infections and infectivity, but it holds that the infecting agent is not the real or intrinsic cause of the disease, but only a remote cause. The infecting agent, like all other outside adverse agents, upsets the unstable equilibrium of the *doṣas* in the first instance; this in turn acts on the *dhātus*, producing the disease and its symptoms.[b]

DIGESTION, METABOLISM AND ELIMINATION

According to *Āyurveda*, life and the biological processes are dependent upon the production of heat inside the organism. This body-heat comes out of food which also nourishes and maintains the organism through its metabolic transformations. Ingested food and drink pass into the stomach, become minutely dispersed by the digestive fluid present there, and their assimilable contents turn into a sweet, frothy, mucus-like fluid. This process of digestion, carried out by *agni* (digestive fire), continues until the fluid becomes acid, issues out of the stomach and excites the secretion of thin bile. At this stage it is an assimilable, nutritive fluid known as *rasa*, which is pumped by the heart through 24 major channels and permeates the entire system. *Rasa* constantly moistens, nourishes, maintains and irrigates the organism by processes which are not completely understood.

[a] *CS. Vi.*, **6**; *SS. Śā.*, **15**. 13–40; *SS. Ni.*, **1**.

[b] *SS. Ni.*, **5**. 2.

It also tranquillizes, lubricates and vitalizes the body. While flowing through the liver and spleen it obtains a red colouring matter; this coloured modification of the potent *rasa* is known as *rakta* (blood).[a]

Blood is the first metabolic transformation of the *rasa*, which is thereafter successively converted into flesh, fat, bone, bone-marrow and, finally, semen. These seven elementary bodily constituents are the seven *dhātus*, orginating in the nutritive fluid produced from food.

There are many by-products from this chain of metabolic transformations. Apart from body-heat there is *ārtava* (a special and fiery variety of blood) formed periodically in women between 12 and 50; *ojas* (essence of vitality), a white, unctuous, cool fluid which gives vital power, strength, activity, good voice, bright complexion and acuteness of the senses; breast-milk formed in mothers and valuable for nourishment of the child. The metabolic processes terminate in the openings of the body, each of which has its specific *mala* (excretions). Apart from menstrual fluid and breast-milk formed only in women, the *malas* are urine, stool, sweat, the excretion from the eyes, ears, nose, mouth and hair follicles. Hair, bodily hair and nails are also *malas*. Unlike *dhātus*, which are produced according to bodily requirements, *malas* are produced according to the quantity and quality of food, and according to age, bodily size and physical condition.[b]

The bodily elements are replenished by the *rasa* and other *dhātus* and are maintained in a proper condition by gathering the necessary ingredients directly from *rasa*, and indirectly from food and assimilated drugs and passing out the excess matter and unwanted constituents. This replenishment and maintenance is a normal and self-regulating process when the various metabolic processes go on without interruption or obstruction through their allotted channels. Blocking, depletion or over-production of any metabolic product prevents proper nourishment and leads to pathological conditions by obstructing or upsetting the humoral balance. Treatment in such cases, and also for non-elimination of *malas*, consists in rectification, restoration or elimination by proper dieting, use of suitable drugs relieving blocked channels, therapeutic processes, blood-letting and other forms of surgery. Food being at one end of a metabolic chain and eliminations on the other, improper or obstructed elimination require as much attention as any other metabolic disturbance.

MEDICAL ANTHROPOLOGY

According to *Āyurveda*, medical treatment should be oriented not only to diseases but also to the patient and the prevalent climate, season and environmental factors. In fact, the patient is considered to be the premier factor in deciding upon a course of treatment. Different treatments are necessary for patients of different ages, sexes, races, castes, habits, habitat, diets, physical conditions, physiological constitutions, vitality,

[a] *CS. Ci.*, **15**; *SS. Sū.*, **14**.

[b] *CS. Sū.*, **28**; *SS. Sū.*, **14** and **15**.

appetites and metabolisms, even when their symptoms are identical. A proper case history should include all these factors. There is also the possibility of a hereditary malady which requires different treatment from an acquired condition with the same symptoms. A patient who has suddenly changed his place of residence, or his accustomed diet, or has been exposed to an unaccustomed climate, also requires special treatment. A physician should also be under no illusion about the special difficulties involved in treating noblemen, high-ranking officers of the State, learned pundits, persons with high-strung nerves, laymen with pretensions to medical knowledge, sly or secretive persons, persons without relatives or friends, destitutes, persons lacking self-control, sex-conscious women, very old people and infants.[a]

Persons with certain anatomical features, like disproportionately short necks, wide shoulders, muscular chests, large faces and foreheads, deep voice and deep inspirations while breathing, are generally immune to diseases and respond quickly to medical treatment. They are generally long-lived. But persons with prominent noses, eyes with tendency to roll, narrow backs, chests covered with curly hair, and unusually large generative organs, are prone to diseases and respond very tardily to treatment. They are generally short-lived. Persons with none of these features are average. The first type requires simple and minimum treatment while the second requires careful, intensive and prolonged treatments.[b]

MAINTENANCE OF HEALTH

It has been said earlier that diseases are the results of aggravation of the humours, and that an inherent imbalance of the humours in greater or lesser degree is present in all human beings, with potentiality of aggravation by wrong food, practices, accidents, etc. The best way to avoid diseases, therefore, is to keep a strict check on diet, habits and hazards which are likely to cause such aggravation. Similarly the best way to gain in health and vigour, both physical and mental, is to live in such a way that the inherent humoral imbalance is gradually rectified or counterbalanced. With these ends in view, *Āyurveda* has formulated an extensive series of rules concerning daily and seasonal diets, routine, and conduct which can maintain, and gradually improve, physical health and mental level, ward off senile decay and promote longevity.

Meticulous cleansing and ablutions are given a special importance in such routines. The locations of the body where the *doṣas* can be easily provoked or get blocked are to be cleaned daily. These include the teeth, tongue, oral cavity, throat, eyes and the entire skin surface. The free movement of the three humours, blood and other bodily fluids can be assured by regular and regulated physical exercise avoiding overstrain and exhaustion. Walking is recommended as a good form of exercise. The

[a] *SS. Sū.*, **10.** 6–7.

[b] *SS. Sū.*, **35.**

malas of the body (including nails and unwanted hair) should be regularly eliminated or removed. Shoes, umbrellas, headgear and clothing should be used against accidental injuries and harmful exposure, both of which aggravate the humours. Living-rooms and beds should be designed to the same ends and to secure the best in relaxation and sleep, both of which can correct humoral derangements. Habits which aggravate the humours, or conduct which provokes them or leads to accidental injuries (which can rapidly derange the humours), should be avoided; those which rectify, should be cultivated. Diets and habits should always be adjusted to seasonal, climatic and geographical factors.[a]

Āyurvedic texts give detailed descriptions of the physiological actions of all edible and potable substances, even organic substances used for smoking purposes. Such lists and descriptions make the selections of diets for all types of personal requirements quite easy. The different tastes of all foods and drugs are given special importance for indicating their potentiality to augment or rectify the *doṣas*. This is said to be due to the fact that the specific tastes (the bland neutral taste exemplified by water; six pure tastes, e.g. sweet, sour, saline, bitter, pungent and astringent; and their combinations taking two, three, four, five and all at a time, making 63 tastes in all) emerge in different substances from the collocations in different combinations and proportions of the five primal elements comprising them, these elements having intrinsic properties which can augment, rectify or counterbalance the different humours.[b] It follows that a judicious selection of edible and potable substances from the different taste groups can maintain health and cure diseases.[c]

All Āyurvedic texts agree that forcible suppression of natural urges—vomiting tendency, sneezing, hunger, thirst, sleep and breathing—lead to immediate and mounting aggravation of the *doṣas*. Sudden changes of temperature, prolonged exposure to intense cold, heat or glare, long spells of strenuous work, over-exercise, carrying heavy loads, personal encounters with stronger enemies, falls from mounts, violent emotions, mental shocks and improper sexual practices have same effects in a greater degree. All these should be carefully avoided by persons desiring health.[d]

SLEEP AND DREAMS

The phenomena of sleep and temporary loss of external consciousness have exercised the imaginations of natural philosophers from the earliest times in all countries. Modern science has many theories on the subjects, but the real nature of sleep, dreams and the unconscious state is not yet understood. It is therefore of great interest to know what *Āyurveda* has to say about these mysterious, twilight periods of human existence.

According to the *Suśruta Saṃhitā*, *nidrā* (sleep) is a natural function of all living creatures and occurs whenever the centre of consciousness

[a] *SS. Ci.*, **24.**
[b] *CS. Sū.*, **26.** 14–81; *SS. Sū.*, **51** and **52.**
[c] *SS. Sū.*, **50** and **52.**
[d] *SS. Ci.*, **24.**

(*cetanā*) is overpowered by an accumulation of *tamas* (essence of inertia). In this condition the sensory channels of the body are blocked by *śleṣman* of a special variety containing abnormal amounts of the *tāmasika* (inertia) principle which has accumulated. In sleep, the *jīvātmā* (*karmapuruṣa*) which never sleeps may give glimpses of occurrences and experiences of previous existences to the *rājasika* (active) principle of the mind in the form of dreams. The *rājasika* principle being the essence of energy and activity retains some of its consciousness even in the pathological state of sleep, but is unable to bring back the normal state of consciousness.[a] In sleep the soul may also give indications of physical weakness, ill health, impending diseases or death, also in the form of dreams, to the semi-awake *rājasika* principle. Normal consciousness returns when the sensory channels have been freed by the agency of the *sāttvika* (conscious and transforming) principle and the being awakes from sleep.[b]

When *sāttvika* and *rājasika* principles are feeble and subdued by any reason, the second fails to maintain partial and potential consciousness and the first to carry out its awakening function. This lasts until these principles are restored to strength and the organism remains in a state of *tāmasika nidrā* (sleep pervaded by inertia) in the form of unconsciousness or coma. This condition, though apparently akin to deep sleep, is quite different from the latter. In *tāmasika nidrā*, the accumulation of inertia and *śleṣman* of the *tāmasika* type may be so great that it is prolonged indefinitely or permanently, culminating in death.[c]

ĀYURVEDA: PRACTICE AND APPLICATION

ETHICS OF THE MEDICAL PROFESSION

A practitioner in Āyurvedic medicine was expected to be a qualified person in all senses of the term. The qualities demanded for this calling were self-control, courage, compassion, integrity of character, keen intelligence, retentive memory, insight, acuteness of perception, purity of mind and body and, of course, a thorough knowledge of the theoretical, textual and practical branches of medical science. These qualities were assured as far as possible by limiting studentship to healthy, well-born youths who could be expected to have the proper potentialities and special aptitudes for learning. The student graduated into the profession only after a long period of study and practical training under competent, inspiring teachers. The intending physician was free to choose a particular branch of Āyurvedic knowledge as his special field, but was required also to have an adequate knowledge of the other branches and as much as possible of other sciences and philosophies which help in giving a comprehensive grasp of *Āyurveda* and the real significance of its diverse informations and its philosophical

[a] *SS. Śā.*, 4. 32–35. [b] *SS. Sū.*, 29. 23–29. [c] *SS. Sū.*, 4. 32–35.

basis. Before starting practice he had to demonstrate beyond all doubt that he had thoroughly mastered his subject and had been properly trained in making independent observations and practical applications of his knowledge. Only then was he given permission to practise independently. A State licence was also required.[a]

Aspirations to success, wealth and fame were considered normal on the part of a physician, but obligations to society and patients must always have prior claims. Desertion of, or injury to, patients under any circumstance was strictly forbidden. A physician's duty is to treat all deserving persons to the best of his ability. But habitual sinners, morally degraded and depraved persons and professional killers (even of animals) were not considered deserving persons.[b]

When a physician takes up a case, he should whole-heartedly apply all his skill, faculties and knowledge to his work. He should remember that patients trust their physicians implicitly to the extent of placing their lives unhesitatingly under his care. This is true even of patients who have no trust in their own relations, parents and children. Hence a physician should take as much care of each and every patient as he would of his own child.[c] He may, however, refuse to take up cases where the disease appears to be incurable.[d]

The physician was expected to place the maximum facilities possible at the disposal of his patients, maintain a nursing home and dispensary, prepare medical prescriptions from raw materials under his own supervision and arrange for the services of nurses and qualified attendants.[e] In private practice, he must not enter a residential house without proper introduction, nor attend a woman in the absence of her husband or guardian. He must not also say or do anything which might give a mental shock to the patient or to the relatives and friends of the patients. He must not divulge any information he had learned in his professional capacity.[f]

A physician should remain a learner all his life, gaining experience, knowledge and understanding all the time. He should discuss problems with other physicians and take part in debates and discussions. He is expected to lead a disciplined and unostentatious life, to be pleasant in his manners and speech, and considerate in all matters. Friendship towards all, compassion for the ailing, devotion to his noble profession and a philosophical attitude to cases with fatal endings—these are declared to be the four corner-stones of medical practice.[g]

CLASSIFICATION AND DIAGNOSIS OF DISEASES

Diseases are the manifestations of the three humours, in their abnormal states, in an organism which already has a propensity for humoral

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[a] *CS. Vi.*, **8**. 3–13; *SS. Sū.* **2**, **4**, **5** and **10**.
[b] *CS. Vi.*, **8**. 13, 20; *SS. Sū.* **2**. 5.
[c] *CS. Sū.*, **25**. 24–25.
[d] *CS. Sū.*, **10**. 8.
[e] *CS. Sū.*, **15**.
[f] *CS. Vi.*, **8**. 13.
[g] *CS. Sū.*, **9**. 26.

aggravation due to inherent imbalance of humours. Hence *Āyurveda* has classified diseases by the humour affected (also in some cases by blood, which can be vitiated), and also by the causes which can trigger off such aggravations.

Classified according to humours (or blood), diseases are of the following types: due to *vāyu*, due to *pitta*, due to *śleṣman*, due to blood, due to two of them at a time, and due to three of them at a time. When all the three humours are deranged simultaneously, the disease is of the *sānnipātika* type and expected to be severe or even fatal. Classified according to the causes which aggravate the imbalance, all deviations from the healthy state are of three types. The first type, *ādhyātmika* (generated inside the organism or the mind), can be of three origins: *ādibalapravṛtta* (inherited from the stage of sperm-ovum), *janmabalapravṛtta* (acquired after conception but before birth, from the mother, her behaviour and other environmental factors) and *doṣabalapravṛtta* (caused during life by improper conduct, diet, etc.). The second type, *ādhibhautika* (due to adverse outside causes), can be of two origins: *saṃghātabalapravṛtta* (due to painful physical contacts, accidents, poisonous bites, etc.) and *kālabalapravṛtta* (due to abnormal or climatic conditions). The third type, *ādhidaivika* (due to fate, malign influences and other unknown reasons), can also have two origins: *daivabalapravṛtta* (providential, caused by 'acts of God', demoniac influences, charms, spells, natural calamities and epidemic diseases) and *svabhāvabalapravṛtta* (caused by factors which become inevitable with time, like sleep, hunger, thirst, senility and death).

The above classification is found in the *Suśruta Saṃhitā*.[a] The *Caraka Saṃhitā* gives only three major origins: *nijaśarīradoṣaja* (of humoral origin, generated inside the body), *āgantuja* (communicated from outside) and *mānasa* (mental diseases).[b] The later texts by Vāgbhaṭa, Mādhava, Cakrapāṇidatta, etc., also give elaborate classifications and subclassifications on the general lines given by Suśruta but differing in details and nomenclature.

All the major texts are also in agreement regarding the principles on which diagnosis is possible, though in some cases like the *Mādhavanidāna*, many chapters are devoted to a learned elaboration of the simple principles. In every case the aetiology, symptoms and prognosis are to be studied and compared to those described in the authoritative texts for different diseases. But, in diagnosis, the personal factors which cannot possibly be found in texts are of major importance. The patient's age, social status, heredity, usual residence, occupation, physical features, hardiness, vitality, habits, accustomed diet and usual appetite form the background which has to be filled in by interrogation and detailed personal examination by the physician who is advised to take the maximum help from his own trained senses. The physician should carefully observe the patient's present appearance, vitality, voice, acuteness of sense perceptions, clarity of mind, memory,

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[a] *CS. Sū.*, 24. [b] *CS. Sū.*, 1, 19.

any abnormality of behaviour, intestinal and other sounds, pulse, skin, bodily excretions, etc. When necessary, a sample of blood should be drawn and subjected to certain tests. Latent symptoms should be brought to the surface by provocative medication.[a]

Even with all the above knowledge at his command, the physician can make a correct diagnosis and decide upon a course of treatment, only if he has the mental calibre to apply properly his theoretical knowledge (which should be accurate and extensive) of all diseases and their different complications. He should have at his finger-tips the knowledge of the specific sources, exciting factors, preliminary indications, concomitant symptoms, possible complications and aggravations, variations of symptoms according to degrees of severity, period of duration and indications of recovery or imminence of a fatal end.[b] The physician should remember that some pathological symptoms are secondary effects of other diseases and may occur either simultaneously with the original disease resulting in a confusion of symptoms, or become apparent after the original malady subsides.[c]

Though the above-mentioned personal factors are all important in diagnosis there are certain rational principles on which a diagnosis is to be based. These principles are too technical to be discussed here. The reader is referred to any reliable edition of *Rugviniścaya* by Mādhavakara, popularly known as Mādhavanidāna, for a masterly discussion of these principles.

Though symptoms are generally valuable only as indicatives in diagnosis, the physicians should remember that in some cases the specific symptoms (or secondary symptoms) can become so violent and harmful that they should be checked first by any means, as otherwise they may prove more harmful than the disease itself. Symptoms are of three classes: *pūrvarūpa* (indicatory symptoms pointing to a future malady, latent in the system), *prāk-kevala* (specific symptoms appearing along with the onset of the disease) and *aupasargika* (secondary symptoms not specific to the disease, which may develop during the course of disease or after the latter has run its course).[d]

GENERAL PRINCIPLES OF TREATMENT

Treatment in *Āyurveda* is fundamentally a process of restoration and building up, consisting largely of elimination of undesirable ingredients and replacing them (and also inherent deficiency) by desirable ingredients from outside. Except in emergencies, medical measures have always the long-term aim of restoring the lost equilibrium of *doṣas* and *dhātus*, or of stabilizing any imbalance which may be present in a state of apparent health. All drugs and medicinal measures, as also surgery, are employed to these ends; so also are diet and conduct recommended to the patient. In pursuance of these aims, *Āyurveda* makes no distinction between hygienic

[a] *CS. Vi.*, 4. [b] *CS. Vi.*, 4. [c] *CS. Vi.*, 8. [d] *SS. Sū.*, 35. 13–15.

measures, preventive medication and therapeutics, or between items of diet and oral medicine.

Food, drugs, therapeutical and surgical measures, daily routine in health and medical measures in sickness—all are, therefore, oriented to the paramount need of creating an equilibrium of the *guṇas*, *doṣas*, *dhātus* and *malas*, individually and jointly. Only then it is possible to uproot the causes of the disease. These ideas apply equally to the mind and the body; for in the case of the mind the equilibrium can be similarly upset by an imbalance of the *guṇas* beyond normal levels. Mental treatment, therefore, requires psychic catharsis and spiritual rebuilding.

As stated previously, the actual medical measures depend upon the disease; and diagnosis depends upon a host of variable factors most of which are individual. Though there cannot naturally be any hard and fast rules, there are certain common denominators in the Āyurvedic treatment of all pathological conditions. These are *saṃśodhana* (cleansing and evacuative processes), *saṃśamana* (tranquilization and rectification of humours and *dhātus*), *āhāra* (proper drugs taken orally, and diet) and *ācāra* (correct conduct and medical regime). All these apply equally to physical and mental processes, which also must be purified, tranquilized, fed with proper ideas and trained to think in proper lines. So in *Āyurveda* prayers, propitiation, spiritual guidance, exorcism of evil influences, etc., are of as much importance as medical measures.[a]

Public hygiene is also not neglected in *Āyurveda*. People are urged to avoid all filth like offal, broken fragments and dirty grounds. Blowing or picking the nose in public and committing nuisance on a public road are forbidden. Dirty and inadequate dress, crude habits of eating, drunkenness, gambling and associating with prostitutes are considered unhealthy practices to be strictly avoided.[b]

The dictum of Manu[c] not to pollute public waters is in conformity with Āyurvedic teachings. Contaminated waters and waters of public baths are recognized as major sources of ill health and epidemics, and the use of only clean and pure water from natural sources is recommended in all the texts.

SPECIAL METHODS OF TREATMENT IN *ĀYURVEDA*

It has been said earlier that all substances are potentially medicinal drugs as they partake of the properties of the elements constituting them. But the selection of any food or drug in any disease, or for maintaining health, depend upon whether it contains the qualities sought for correcting the humoral state. The intrinsic qualities of all substances are taste, assimilability, potency, physical properties and specific physiological or therapeutic action. All these qualities have to be considered in selection; but taste, assimilability and therapeutic action are more important than the other two.[d] When a single substance is not available to satisfy all the

[a] *Aṣṭ. Hṛ. Sū.*, 2; *SS. Sū.*, 1. [b] *CS. Sū.*, 8. [c] *MS.*, IV. 56. [d] *CS. Sū.*, 26.

desired qualities (as it is very often the case), more than one material is used in combination to meet the ends. Thus arise the *yogas* or prescriptions containing a multiplicity of drugs.

The four initial requirements of Āyurvedic treatment are good physicians, good nurse-attendants, good medicines and methods, and obedient patients.

Among specific therapeutic methods, regular cleansing of accumulated bodily wastes and of internal organs get the pride of place in *Āyurveda*. Other methods (apart from oral medication which is the most common) include eye-drops, eye-salves; gurgles, fumigation of the ear, nose and throat areas;[a] liquid unguents, lotions, creams, skin salves, ointments, medicated oils, medicated clarified butter, etc., for the skin surface;[b] suppositories, tampons, soaked cotton swabs for the bodily openings; enemas, douches, etc., applied by catheter tubes, douche-cans, etc., for the rectal, vaginal and urethral passages;[c] sun-bath, steam, steaming decoctions, hot air and hot surfaces, hot immersion baths, hot fomentation, etc., for sudation and cleansing the skin pores;[d] and fomentation with absorbable drugs, mud-packs and poultices for local medication. The use of water sterilized by boiling or immersion of hot substances,[e] antisepsis by fumigation with benzoin group of drugs, arsenic compounds, use of hypertonic salt solutions for surgical dressings, astringents as styptics for bleeding wounds and abrasions, use of cautery, intense cold and tying blood vessels in uncontrollable haemorrhage and use of alcohol for inducing anaesthesia are found scattered in the texts.

Psychiatric methods[f] are also among the special methods of *Āyurveda*.

ĀYURVEDIC SURGERY

The high achievements of Āyurvedic surgery have been described in an earlier section. The general excellence of Āyurvedic surgery is attested by the remarkably rational concepts and scientific methods found in the texts. Details of such methods are naturally out of place here.

According to Suśruta, surgery is the best, quickest and generally the most successful method of treatment,[g] as it involves total removal of the diseased or morbid accumulations of *doṣas*, *dhātus* and *malas* and gives the organism a better chance to acquire a new equilibrium by post-surgical medication to replenish the removed tissues, fluids, secretions, etc. Surgical treatment, according to *Āyurveda*, is not limited to the use of surgical instruments alone but a complete course of treatment, including diagnosis, preparatory methods and measures, actual operation and post-surgical methods, to aid healing and restoration of health.[h]

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[a] *CS. Sū.*, 5.
[b] *CS. Ci.*, 6 and 7.
[c] *CS. Sū.*, 1, 9, 10 and 11.
[d] *CS. Sū.*, 14.
[e] *SS. Sū.*, 45.
[f] *CS. Vi.*, 6.
[g] *SS. Sū.*, 1.
[h] *SS. Sū.*, 7.

The *Suśruta Saṃhitā* recommends the use of bandages, splints, padding materials, plugs, lints, tourniquets, ligatures, horse-mane, human hair, silk and other threads, boiling and cold water, honey, milk, clarified butter, vegetable oils, pulverized cereals soaked in water, caustic and mild alkalis, heated metals, astringent pastes and solutions, setting plasters, ointments and alcoholic liquids as aids in surgical processes. For the different types of surgical processes (listed as incision, excision, scraping and softening of epidermic layers, puncturing, probing, extraction, draining and suturing) used for various conditions requiring surgery, 24 different manipulative methods (including sucking out, flushing, compression, wrenching, injections, etc.) are described. A great variety of surgical instruments including scalpels, razors, saws, probes, needles, hooks, forceps, pincers, hammers, tubular appliances, hollow hemispheres, horn instruments, speculums, etc., made of tempered hardened iron and other metals are described.[a]

ĀYURVEDIC *MATERIA MEDICA*

Plant and Animal Substances

The *materia medica* of *Āyurveda* is extensive, and utilizes substances from the animal, vegetable and mineral kingdoms. The humoral conception of the diseases and their remedies together made this extensive *materia medica* logical and even compulsory. For, according to the basic theory, the different properties and constitutions of all different substances made them valuable in some condition or other. A study of the Āyurvedic texts makes it clear that the drugs included had each been selected after careful clinical experiments and long experience. The specific properties like taste, assimilability, potency, physiological actions are described in almost all cases.

These experiments were naturally conducted mainly with materials available in the environment, which explains the strong preference shown by classical *Āyurveda* for plant remedies of the indigenous varieties. A second reason for this preference was that the plants being composed of all the five elements (according to the *pāñcabhautika* theory) had a natural flexibility and wider range of application, compared to inorganic matters composed of the earth element only. This advantage was shared by animal products but their use was limited by availability and variety, and possibly by lesser efficiency in actual application. A statistical break-up of the *materia medica* in the *Caraka Saṃhitā* shows 341 plant-substances, 177 drugs of animal origin and 64 mineral substances, metals, etc.[b] The corresponding numbers for the *Suśruta Saṃhitā* are 395, 57 and 64 respectively. The animal products are found less and less in the later works. These numbers no doubt reflect their tradition-*cum*-availability and also efficacy in comparison with each other. But in the case of inorganic

[a] *SS. Sū.*, 7 and 8.

[b] Rây and Gupta, pp. 38–85.

remedies, the choice was limited to the few locally available metals and minerals, the synthesis of new inorganic compounds being still unknown.

Plants provided the natural and traditional drugs for most oral and non-oral medication. A clear understanding of their properties had led to their rational classification into different groups according to therapeutic actions. A list found in *Caraka* gives 50 different groups.[a] But in spite of the wide range of available varieties, many conditions required more than one drug, sometimes of different groups, sometimes in combination with animal and mineral matters also. This multiplicity of drugs for a single disease was based not only on theory but also on experience. If both (or all three, four, etc.) had been found valuable for various conditions, of a disease, it was quite logical to use all of them at the onset of a disease, when the prognosis was still not known. In this way, with new experiments and new clinical experience through centuries, more and more ingredients would enter into a single prescription, in the hope of possible benefit to the patient, due to inherent conservatism, and finally due to the supposed sanctity of written texts. Nothing would be dropped out against the new additions, and prescriptions sometimes grew to alarming proportions, containing literally hundreds of ingredients. To manage into homogenous form different solid, squashy, semi-solid and liquid substances, a great deal of compounding skill had to be brought into play. Even in the earliest texts we find elaborate directions for extracting the active constituents of organic substances and homogenizing them. Thus developed the remarkable and elaborate processes met with in the *saṃhitās*. Many of them have survived unchanged and form part of modern Āyurvedic pharmacological practice. They are named and sometimes described in detail in various passages while giving instructions for compounding prescriptions or extracting drugs from crude materials. They include the processes of solution, maceration, trituration, extraction with water, preparation of tinctures, preparation of emulsions, or solutions in oily liquids, extraction of essential oils and juices, pasting, coagulation, filtration, decantation, sedimentation, dilution, concentration, precipitation, gel formation, desiccation, dehydration, percolation, evaporation, distillation, fractionation, sublimation, steaming, combustion, chemical combination, etc. Actual weights and volumes were obtained by balances and measuring vessels, and a large number of other apparatus were used.[b] But all these methods were those of the pharmacy. There is little evidence of synthetic preparations of either inorganic or organic compounds. Processes for the dissolution of finely divided iron, gold, silver, gems, minerals, etc., in vegetable acids for medicinal preparations are found in some passages. The use of mercury is referred to in the *Suśruta Saṃhitā*, but only as an ingredient of a cosmetic preparation.[c]

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[a] *SS. Sū.*, **4.** [b] Rāy and Gupta, p. 114. [c] *CS. Ci.*, **11, 12** and **21**; *SS. Ci.*, **25. 20.**

Inorganic and Metallic Remedies

After the age of Caraka and Suśruta we find a steadily increasing complement of inorganic substances among Āyurvedic medicines. The incoming materials differed from the readily available and naturally occurring inorganic substances mentioned in the earlier works; most of them were synthetic substances or minerals and ores transformed by chemical processes or metallurgical treatment. The beginning of this trend is found in Vāgbhaṭa's works. These inorganic medicaments got a fillip from the researches of many generations of alchemists and iatrochemists who discovered many valuable chemical and metallurgical processes and devised new and workmanlike apparatus for their work. How these substances came to be used as medicines cannot now be ascertained with any accuracy, but the 'philosophy of mercury' and the prestiges of Vṛnda and Cakrapāṇidatta who first gave them a status as medicine must have helped. The advantages which gave these medicines an ever-increasing popularity among medical practitioners during the centuries have been recounted earlier. Another possible reason was that they often proved valuable in conditions which would otherwise have needed surgery, for which there was a growing distaste in the profession.

The processes and apparatus devised during this age belong properly to the history of chemistry in India. The mercurial preparations, however, occupy a special position in this field and a short account of them will furnish a sample of the notions and methods of Āyurvedic chemistry of the *Rasacikitsā* school.

Mercury of a pure variety was obtained by the dry distillation of pure *hiṅgula* (cinnabar, HgS) in a retort and collecting the vapours in cold water (*Rasaratnasamuccaya* quoted in Sir P. C. Ray's work). Mercury obtained from impure cinnabar or imported from outside contained toxic matters, lead, tin and other impurities and required re-purification to make it fit for internal medication. This purification was done by trituration in a mortar with certain (named) vegetable juices in several repeated operations, each alternated with washing by portions of cold water. It was finally distilled thrice in a clean retort and receiver luted with clay.

Mercury is said to be 'solidified' by rubbing with gold or silver giving a bright, brittle, solid product. It can also be 'solidified' by roasting in a covered crucible with its own weight of sulphur and one-eighth its weight of gold. (These processes would not really result in the solidification of the liquid metal; by the first process mercury will be converted into an amalgam and by the second into a pasty mixture of the metal and its sulphide.)[a]

Mercury is said to be 'incinerated into an ash' by prolonged trituration with certain mixtures containing oils and juices of vegetables, followed by heating the mixture in a covered crucible.[b] (The 'incineration' of mercury

[a] Ray (P. C.), I, p. 54; II, p. 4.

[b] *Op. cit.*, I, pp. 73–74.

into an ash is *prima facie* impossible; the metal may be converted into solid crystallizable derivatives by these processes.) Cinnabar, heated in a closed crucible with other plants, is said to give powdered ashes of mercury. By triturating the metal with yet other plant juices, alternatingly heating and cooling the mixture seven times, and finally heating in a closed crucible with fresh quantities of the plant juices is said to result in a salt-like ash of mercury.

Mercury is said to be 'killed' by distilling with an excess of sulphur. The red-brown sublimate of mercuric sulphide is known as *rasasindūra* or *makaradhvaja* and is believed to be a highly potent remedy for many diseases and for senile decay. Mercury heated on a sand bath with twice its weight of resublimed sulphur, and one-eighth its weight of pure gold is known as *siddha-makaradhvaja* supposed to be comparable to ambrosia in its efficiency. Some later works of the same *Rasa* school are rightly sceptical about the incorporation of gold into the sublimed product. They believe that gold is simply left behind, and hence it makes no difference whether gold is used or not, and that there is no difference between the two varieties of *makaradhvaja*. The varieties of *makaradhvaja* are fairly representative examples of this class of medicines. After many centuries of experience, their efficacy is no longer open to question, though not all that it is claimed to be. Their use has survived up to modern times.

VETERINARY SCIENCES

The description of *Āyurveda* as a comprehensive science of life and not as mere medical science is further justified by the existence of branches dealing with the welfare and treatment of other living creatures besides human beings and even of trees. This inclusion is logical, for, according to Āyurvedic treatises, the *raison d'être* of this science lies in compassion for all forms of suffering. On a more practical plane also, the proper care of livestock and economic vegetation was highly important to a non-industrial economy based on natural resources and on animals for nutrition power and transport. A knowledge of the level of veterinary knowledge in ancient India is obtained from specialized and individual treatises dealing with cows, horses and elephants. The *Rājamārtaṇḍa*, an encyclopaedia of medical knowledge by Bhojarāja (available in a printed edition published by the Āyurveda Granthamālā series, Bombay), contains extracts from the above treatises and also deals with water-buffaloes, deer, dogs, falcons, pigeons, etc. The *Yogasudhānidhi* by Vandimiśra[a] contains a chapter of conception, obstetrics and special diseases of female animals.

BOVINE *ĀYURVEDA*

The nutritional and therapeutic values of milk are described even in the earliest Vedic literature. The *Suśruta Saṃhitā* gives a detailed account

[a] Sen, Gananath (2), p. 76.

of similar values of milks of other animals and the products obtained from them.[a] This and other passages scattered in Āyurvedic works refer to examination and care of milch cows. A treatise dealing exclusively with *Gavāyurveda* (medical knowledge concerning bovine animals), attributed to Gotama, must have been current up to the middle ages, as quotations from it are found in the *Rājamārtaṇḍa*, but no authentic version is known at the present time. This treatise contained information relating to mating, stud bulls, calving, possible retention of the placenta, lactation, sources of contamination of milk and insuring the best quality of milk, diet in health, diseases and pregnancy, and bovine ailments in the shape of fevers, gastro-intestinal troubles, skin affections, ulceration of udders, loss of milk, sterility, etc., and their treatments.

EQUINE *ĀYURVEDA*

The *Saṃhitā* of Śālihotra, an ancient and famous treatise dealing exclusively with horses, of which extracts are found in the *Agnipurāṇa*, was, according to some, redacted by Kalhana (twelfth century) under the title *Śālihotrasārasamuccaya*.[b] A translation in Arabic of either the original work or its redaction was made in the age of the Caliphs of Baghdad, and was known as *Sālātor*. Other important editions or redactions of this work are *Aśvavaidyaka* by Jayadattasurī and *Aśvaśstra* by Nakula. The first work is a large volume of 68 chapters dealing with many topics, including separate chapters on different breed of horses; their characteristics according to age, sex and breed; the features to be desired or preferred in horses for riding, for drawing carriages and for stud purposes; foaling: lactation; diet; various types of internal medicines and external applications for equine diseases like cough, indigestion, diarrhoea, skin diseases, apoplexy madness, etc.; and surgical operations for treatments of malformations, diseased conditions castration, etc. The medical and surgical methods follow the classical precepts of *Āyurveda*. Nakula's work is remarkable for its coloured illustrations of horses and knowledge of equine anatomy. It is also a valuable compendium of many branches of knowledge relating to horses. An Āyurvedic lexicon, also credited to Nakula, named *Cikitsā Saṃgraha*, contains a glossary of terms and *materia medica* relating to this branch of knowledge. Bhojarāja's encyclopaedia quotes also passages from *Hayalīlāvatīnāmasaṃgraha* by Jayadeva, *Vājīcikitsā Saṃgraha* by Jayadatta, and *Sārasaṃgraha*, an anthology of different works on this subject, by Nakula. These works are of minor importance and are also rare or unavailable.

ĀYURVEDA OF ELEPHANTS

In ancient India elephants were in constant use for military purposes, as mounts and for moving heavy loads. The care of elephants became

[a] *SS. Sū.*, 45.

[b] Sen, Gananath (2), p. 76.

naturally an important branch of veterinary science. An exhaustive treatise on *Hastyāyurveda* (*Āyurveda* of pachyderms), rivalling the *Caraka Saṃhitā* in bulk, is attributed to the sage Pālakāpya, but it may be the work of one of his disciples, for it is, like the *Caraka Saṃhitā*, written in the form of questions and answers between the sage and his disciple Romapāda.[a] This branch of medical knowledge is also based on the *tridoṣa* theory of origins, symptoms and treatments of diseases. The *Pālakāpya Saṃhitā* is divided into four sections, *mahārogasthāna* (on major ailments), *kṣudra-rogasthāna* (on minor ailments), *śalyasthāna* (on surgical treatment) and *uttarasthāna* (detailed treatment of some topics), and includes chapters on anatomy, physiology, habits, mating habits, seasonal changes, stabling, food, sterility and madness of elephants. The symptoms of diseases and their treatment and the prognosis of imminent death of elephants are also discussed in the text.

PLANT *ĀYURVEDA*

The terms *vṛkṣāyurveda* (science of life of trees), *gulmavṛkṣāyurveda* (science of plant life) and *bheṣajavidyā* (science of medicinal plants) occur in ancient works like the *Arthaśāstra*, *Agnipurāṇa* and *Bṛhatsaṃhitā*, and refer to selection and procurement of viable seeds, choice of proper soil, irrigation, manuring, sowing and germination of seeds, planting, grafting, pruning, layering, seasonal care, cultivation, rotation of crops, climatic conditions in relation to proper growth, classification and identification of plants, aesthetic and hygienic values of gardens, construction of herbariums and the treatment of plants in healthy and diseased conditions. Many of these topics can be classed as medical knowledge relating to plants. This unique branch of *Āyurveda* survives now only in scattered references in the above works and specially in a chapter of the comprehensive medical treatise by Śārṅgadhara (thirteenth century) entitled *Upavanavinoda*.

The *Suśruta Saṃhitā* mentions the respective roles of seeds, climatic conditions, soil and water in the germination of plants.[b] *Upaskāra* by Śaṅkaramiśra, displays an intimate knowledge of botany in stating that 'water poured at the roots goes upwards and laterally through the interior of a tree, where neither impulse, nor impact, nor even the solar rays can cause the movement; the coherent medium of water and causative living soul in the trees and plants make the moisture rise upwards and the trees grow'. The *Bṛhatsaṃhitā*, *Manusaṃhitā* and *Arthaśāstra* contain practical methods for propagation and reproduction of plant, though the phenomenon of sexual reproduction in plants was not realized. An extensive nomenclature of thousands of types of trees and plants is found in all relevant works, but the classification of flora was based not on families and genus but on external or floral characters and medicinal or dietic values.[c]

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[a] Filliozat (2), pp. 164–75. [b] *SS. Śā.*, 2. 33. [c] *CS. Sū.*, 4 and 27; *SS. Sū.*, 47.

The etiology, diagnosis and treatment of plant diseases (and also of plant blights and sterility) are dealt with in the *Upavanavinoda*, mentioned above, which also contains chapters on classification of plants, selection and sowing of seeds, watering and care of plants, recipes for nourishing (culture) solutions, and different methods of propagation, including *bījaruha* (by seeds), *mūlaja* (by roots), *skandhaja* (by cutting operations), *skandharopanīya* (by grafting and layering), *agravīja* (by apices) and by *parṇayoni* (inside leaves). It also contains some interesting speculations on the possibility of creating new species of plants with desired scents and colours in its products, anticipating the modern science of applied biology by nearly two thousand years.

SPREAD OF *ĀYURVEDA* OUTSIDE INDIA

THE *ĀYURVEDA* IN ANCIENT IRAN AND THE HELLENIC COUNTRIES

It has been noted earlier that there is a close analogy between the medical traditions of the two branches of the Indo-Aryan family in Iran and India. Even after the period of the Veda and the later *Āvestā*, many of the basic conceptions are found to be the same, due perhaps to close communication between the two, though the methods of treatment and theories of medicine differ.[a]

An ancient Mesopotamian medical manual, possibly dating back to the Hammurabian period (*c.* 2000 B.C.), contains many medical concepts which reappear in changed but unmistakable forms in Indian *Āyurveda* and the Hippocratic tracts on medicine. The supposed special symptoms of imminent death, found in this work, are found in a modified form in *Pre-notions de cos*, *Coan prognoses* and *Prorrhelique I.* They are also found, though in a less archaic and empirical form, in practically all Āyurvedic texts.[b] This general concordance between the ancient Mesopotamian system and the later Indian and Greek ones is also strikingly observed in the case of symptoms of demonic possessions, specially of children.[c] But, in this case, the *On the Sacred Diseases* of the Hippocratic collection gives examples and symptoms but rejects the theory of supernatural origin. As far as these and some other common ideas are concerned, there is no reason to believe that such ideas originated in Indian medicine and was transmitted to Greece or vice versa.

But many other concepts of Greek medicine are extremely likely to have been Indian in origin and development and are likely to have been propagated by the spread of Indian medical ideas in many countries, by direct contacts, and by indirect communications. In the case of Greece there was communication from very early times, at least as far back as

[a] Elgood, pp. 19 ff.
[b] *Bhela Saṃhitā, Indriya,* **12**; *CS. Indriya,* **12**; *SS. Sū.,* **29–33**; *Kāś. S. Sū.,* **8**; *Aṣṭ. Hṛ. Śā.,* **5** and **6**; *Aṣṭ. Saṃ. Sā.,* **9–12**.
[c] *SS. Uttara,* **27–37**.

the fourth century B.C., even before Alexander the Great invaded the Indus valley (327 B.C.). His army physicians did not know any cures for snake-bites and other diseases endemic to the area. Indian doctors were called in and some of them later accompanied the returning army back to Greece.[a] Thus began the spread of *Āyurveda* in the Hellenic Empire, though fragments of *Āyurveda* knowledge must have found their way earlier through Iran and the maritime trade routes, as shown by the fact that substances like pepper, cardamoms, musk-root plant, indigo and cane-sugar, indigenous to India at that time, are found among the earliest exports of India to Greek ports.

The clear enunciation of the theory of an internal and vital organic breath (akin to the cosmic wind) as the cause of all motor activity of the living body and its involuntary muscles, as well as that of movements of fluids circulating inside the body, is part of the ancient works *Bhela Saṃhitā*[b] and *Agniveśa Saṃhitā*. A much less precise version of this thesis is found in the Hippocratic texts *On Breaths*, where bodily wind is simply stated to be 'the cause of the principal phenomenons which accompany the fevers, shivering, trembling, yawning, resolution of articulation, transpiration, etc.'[c] The Hippocratic tracts had their origin mainly between the fourth century B.C. and third century A.D., and do not antedate the *Bhela Saṃhitā* and the *Agniveśa Saṃhitā*. The treatment of this theme in the *Caraka* and the *Suśruta* is much more elaborate and sophisticated, showing a gradual local development. Many scholars trot out the theory of later interpolations or even past forgeries when Indian texts show a higher development in any concept compared to later or contemporary Greek texts. These arguments, however, can cut both ways. Again, the typically Indian concept, found in many basic Indian philosophies of ancient origin, of the creation of the embryo at the moment of conception, by the simultaneous congress of the *puruṣa* (self-existent eternal soul), the vital breath, the parental semen and the maternal seed, is found in a somewhat changed form in the Hippocratic text, *On the Nature of a Child*. In this latter work, the mention of a maternal 'semen' is unique in Greek medicine, though the idea is very common in Āyurvedic texts. The reference to *puruṣa* as an ingredient is also lacking. The ideas of the vital breath starting at the moment of conception to build up the anatomy and physiology of the foetus from the fundamental elements is also found in the texts *On the Embryo of Eight Months* and in *On Flesh*. But the details about the instantaneous commencement and the ingredients are lacking. The idea of the mother's vital breath, found in all Āyurvedic texts, circulating also through the embryo is also found in the *Embryo of Eight Months*, but the details about the embryonic heart, embryonic blood-circulation and nutrition are lacking. The attribution of diseases of the nervous system to obstructed and vitiated wind is a special and remarkable theory of *Āyurveda*. In *On Diet in Acute Diseases*, only a few such diseases like

[a] Arrian, p. 229. [b] *Bhela Saṃ., Sū.*, 16. [c] Filliozat (2), p. 222.

sudden loss of speech, giddiness, convulsions, etc., are attributed to obstructed wind without formation of any coherent theory. It is logical to suppose that these ideas which are found developing progressively in Indian medical literature were not Greek in origin and further that they were imported into Greece along with many other Āyurvedic concepts, some clearly discernible, others changed beyond possible recognition.

The humoral theory of origin of diseases is another instance in point. There is a steady development of this concept, beginning with a mere mention in the *Ṛgveda*; followed by the enumeration of the three humours in the *Atharvaveda*; then a visible and clear formation of the theory in the *Atharvaveda-pariśiṣṭa* (a later appendage of the *Atharvaveda* in the latest period of Vedic literature); then its emergence as a comprehensive theory of causation, symptoms and treatments of diseases in the *Bhela Saṃhitā*; and finally its all-embracing form in the *Caraka* and *Suśruta Saṃhitās* as a complete explanation of all vital processes, their imbalances and their cure. It is possible that the Greek development of the theory was independent of India. But as it is found in Greek texts in less sophisticated and less complete forms in all comparable periods, the presumption that it travelled from India to Greece is justified. The time lag explains the lacunae and imperfections in the Greek theory and also the somewhat irrational addition of blood, one of the visible bodily fluids, as the fourth humour.

Megasthenes, the Greek ambassador to India towards the end of the fourth century B.C., tells us how the diseases of elephants are to be cured, and gives prescriptions which are clearly borrowed from the *Hastyāyurveda* of Pālakāpya.[a] The Āyurvedic dry *pippalī* (long pepper), used in prescriptions for the eyes, is metamorphosed in the Greek manual, *On Woman's Diseases*, as the Median medicine *peperi* for the eyes, and in *On the Nature of Woman* it is *midikhoi* medicine and not acknowledged as *indikhoi* (Indian). Other passages in the former text confirm that Median is a wrong reading for Indian.[b] These and many other facts and logical inferences prove that *Āyurveda* spread into Greece and the Greeks were perhaps unaware that they were using borrowed concepts and data. The reverse process has also probably occurred in many instances.

THE *ĀYURVEDA* IN THE ARABIC WORLD

The spread of *Āyurveda* in Arabic countries is well authenticated and not based on inferences. Due to the meticulous habit of Arabian scholars of keeping complete records of historical and cultural events, it has been possible to get a clear picture of the prestige and popularity of Indian medicine in this area from historic times. The considerable amount of surviving literature in Arabic and Persian on medicine contains many translations from Indian treatises and much material that is directly utilized

[a] Filliozat (1), pp. 194–95.

[b] Filliozat (2), pp. 253 ff.

from them. The medical scholars of the two lands, who travelled freely from one country to the other before and after the Islamic conquest of India, have contributed much to a mutual enrichment of knowledge. The science that the Arabs carried with them in their far-flung empire must have contained a fair amount of Indian contribution, specially in medicine, just as they brought much of Syrian and Greek science to their Indian Empire.

The Arabs established trading centres in the Malabar Coast of South India in the seventh century and carried away spices, dyes, drugs and scent materials to their other centres in Asia, Asia Minor, Africa and Europe. This made the world of Arab trade conscious of the quality of Indian drugs. In the eighth century the Arabs conquered the Indian province of Sind. The cultural genius of the Abbāsid rulers, curious about the long reputation of Indian science and specially Indian medicine, began to send scholars to India and invite Indian scholars to visit them. Thus began an exchange of scientific ideas, by direct contact, between the two countries in philosophy, mathematics, astronomy, chemistry, metallurgy and medicine.[a] A later Abbāsid Caliph, Harun al-Rashid, was famous for his patronage of learning and science. He actively encouraged the learning of the Indian system of medicine and caused some of the classical treatises of India to be translated into Arabic. An emigrant Indian medical scholar became the physician-in-chief of the State dispensary after he was 'successful in curing his royal patient of a long-standing stomach trouble'. This Indian scholar translated the *Suśruta Saṃhitā* into Arabic under the title of *Kilal-Samural-hind-i* of 'Susrud'. The famous scholar Ali ibn Zain translated the *Caraka Saṃhitā* into Arabic as the treatise of 'Sarag'. In later years the *Nidāna* of Mādhava was translated under the title *Badan* and the *Aṣṭāṅgahṛdaya* as *Astankar*. These Arabic works were also retranslated into Persian. The *Āyurveda* thus became a well-known science in Arabia whence it spread into Persia, Turkey, Egypt and the Mediterranean countries, which passed under Arab domination in later ages.

Nearer home, the influence of Āyurvedic system in Iran, even before its conquest by the Arabs, has been clearly established. The Iranian king, Chosroes I (A.D. 531–579), had a physician named Burzūya who had brought a version of the *Pañcatantra*, the Indian Book of Fables, into Iran after a journey to India. The autobiography of this physician contains a summary of embryology which has been recognized by Hertel as containing typically Indian notions. Burzūya, for example, says that delivery is caused by a wind—and this is 'precisely the teaching of classical Indian medicine'. It is, of course, not unlikely that this Indian idea was not introduced by Burzūya, but had reached Iran even before his time, for there is positive evidence of the Indian influence on the famous medical school established in the fifth century A.D. at Gundesapur in Susiana by the Nestorians expelled from the Byzantine Empire. It is interesting to note in this connection that in the chapter dealing with the functions of the 'wind' in the existing

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[a] Reinbold, pp. 315–87; Majumdar (R. C.), II, pp. 276–77.

text of the *Caraka Saṃhitā*, mention is made of the presence of Kāṅkāyana, the physician from Bāhlika (*Bāhlikabhiṣaj*), in an assembly of learned men gathered round Master Ātreya. Bāhlika or Bactria, on the other side of the Hindu Kush mountains, was included in the dominions of Chosroes I. Apart from the writings of Burzūya, this Indian legend has preserved the reminiscence of the close contact between the Iranian and Indian doctors.[a]

There is more direct evidence of the influence of *Āyurveda* further east in Central Asia. Modern archaeological excavations have unearthed the remains of a large number of ancient cities that lay buried deep under the sands for more than a thousand years, along the trade route from Bactria to China passing between the Tien Shan mountains in the north and the desert of Taklamakan in the south. Many of these old cities were Indian settlements in the early centuries of the Christian era. One of them—Kuchi or modern Kucha—was an important centre of Buddhism and, according to Chinese records, there were nearly 10,000 *stūpas* and temples in this kingdom at the beginning of the fourth century A.D. An Indian became the preceptor of the local king. Music and other arts and sciences of India flourished in this region. The famous manuscript, known after its founder as Bower Manuscript, was recovered from this region.[b] It contains seven Sanskrit texts, of which three are medical treatises. The first deals with the wonderful properties of *lasuna* and other roots and herbs, particularly in curing eye-diseases. The second, *Navanītaka*, is a voluminous text divided into 14 chapters. The third text contains medical formulas in 72 verses. Another work dealing with spells and charms as antidote against snake-bite is also of semi-medical character.[c] Several other manuscripts of medical texts have also been found, including a Kuchean translation of a collection of Sanskrit text and a part of a bilingual manuscript (original Sanskrit text with Kuchean translation) of *Yogaśataka* ascribed to Nāgārjuna or Vararuci.

The influence of *Āyurveda* is also clearly traceable in Tibet. A large number of medical texts in Sanskrit were translated into Tibetan in the eighth century A.D., and there is no doubt that the medical system in Tibet was derived mainly from *Āyurveda*. To mention only a few similarities, reference may be made to the nine openings and 900 nerves in a body, the theory of three humours, the injury caused by taking together fish and milk, and the use of certain herbs and plants as drugs. Several Tibetan medical works were translated into Mongolian, and the Tibetan medical system, based on *Āyurveda*, was adopted by various hill tribes of the Himalayas near Tibet.[d] Indian drugs were known in China, Korea and Japan.

The Hindus who established colonies, kingdoms and empires in Indo-China and Indonesia during the first millennium of the Christian era also introduced the knowledge of *Āyurveda* in these regions. The medical treatise of Suśruta is referred to in an inscription of Cambodia (Kambuja)

[a] Filliozat (1), pp. 198 ff.
[b] Majumdar (R. C.), II, pp. 276–77,
[c] Keith (3), p. 509.
[d] Filliozat (4), p. 69.

and vigour were definitely things of the past; so also were dispensaries, hospitals and medical services maintained at State expense by past Buddhist and Hindu monarchs. The new generations of medical students had to depend upon largely on their personal teachers for practical and theoretical training, augmented no doubt by the great treatises. The main prerequisite of sustained intellectual development—prestige and security of the intellectual and professional classes in a politically stable and progressive society—was gone; for India was constantly overrun by powerful foreign hordes. The martial classes not only ruled the land; they had replaced the intellectuals as the dominant class in the social hierarchy.

It would be, however, an unjustified oversimplification to ascribe this static condition and the later stagnation and decay of *Āyurveda* solely to political reasons. The seeds of decay lay inherent in Indian thinking, religious beliefs and social system, and these profoundly affected the Indian sciences themselves; and medical science was no exception. The intellectual curiosity and passion for experimental research, which were associated with the Tantric and *Raseśvara* faiths, also petered out due to the same inherited factors.

But, during the broad period of Indian history (A.D. 1200–1800), the residual impulse of the vigorous medical systems of the earlier ages produced an impressive array of valuable secondary works before reaching almost complete inertia. This inertia was helped by the adoption of *Unani* (originally Arabic) medicine as the system recognized by the ruling power along with a passive neglect of *Āyurveda*. This loss of prestige was followed, as we shall see, by a loss of popularity as well, during the last centuries of this period.

ĀYURVEDIC WORKS IN THE MIDDLE AGE

Many scholarly works on *Āyurveda* proper were written during these six centuries. One of the earliest was the *Saṃhitā* of *Śārṅgadhara* (thirteenth century), which, for the first time in the history of Āyurvedic works, includes opium in the *materia medica*, possibly following Chinese or Arabic practice; mercurial and other metallic compounds are also freely used in the text. A voluminous and possibly later treatise is by Vaṅgasena, with the title *Cikitsāsaṃgraha*. This work, which is not to be confused with an earlier work of the same name by Cakrapāṇidatta, has always been known as *Vaṅgasena*, possibly to avoid this confusion. It has been a popular handbook in Bengal for many centuries and is available in all respectable collections. The author claims in a concluding colophon that his work is a redaction of an earlier *saṃhitā* by the sage Agastya of South India fame and the legendary originator of the Sittar school of pseudo medicine. But, though it contains many prescriptions from this school, its language and presentation prove its later date of composition.[a] The *Yogaratnākara*,

[a] Sen, Gananath (2), p. 59.

another comprehensive and monumental treatise on *Āyurveda* by an unknown author, has been popular in South India for many centuries; its chemical methods for preparing drugs are extremely valuable. Possibly the most renowned work during this period is that of Bhāvamiśra (fifteenth-sixteenth century). This work, *Bhāvaprakāśa*, contains an exhaustive list of diseases and their symptoms and a complete list of drugs current in his time. This encyclopaedia includes the aetiology and treatment of syphilis, a disease introduced into India by Portuguese seamen in the fifteenth century. Its list of drugs includes many that were not previously included in Indian medicinal usage, including metallic preparations and imported drugs.

Another class of medical works, which had existed from earlier times but which became increasingly important as handbooks in medical practice during this period, were the *nighanṭus* (ready guides or lexicons), which contained long or short monographs on different medicinal substances and terms. The works of this period were by Madanapāla, Narahari, Bhīmapāla and Rājavallabha, which supplemented or supplanted earlier works by Dhanvantari, Halāyudha, Viśvadeva, Amara, Śeṣarāja, Soḍhala, Mādhava and Cakrapāṇidatta. None of these works claim any originality in matter or presentation of theoretical knowledge. Among specialized treatises of this period may be named *Arkaprakāśa* by Rāvaṇa, of unknown age (possibly of a date not later than the twelfth century as indicated by the style of writing), dealing with aqueous and tinctorial extracts; *Cikitsākalikā* by Triṣaṭa (fourteenth century), a manual on diagnosis; *Cintāmaṇi* by Ballabhendra (fifteenth-sixteenth century), another comprehensive work on aetiology and diagnosis of diseases and clinical examination of the bodily eliminations; *Vaidyāmṛta* by Moreśvara (early sixteenth century), dealing with treatment of diseases only; and *Vaidya-Jīvana* by Lolimbarāja (seventeenth century), dealing with the clinical and therapeutical aspects of marital relations. Most of the works mentioned above are available only in manuscript form. An assessment of these works has been given by Gananath Sen (2) and Keith (3).

WORKS ON *RASACIKITSĀ* AND IATROCHEMISTRY

The works of the *Rasacikitsā* school of this period compare favourably, in material and presentation, with earlier works of this branch of medical and chemical knowledge. *Rasaratnākara*, the monumental work by Siddha Nityanātha in five volumes, was the earliest work of this period, though it might have been composed in the last years of the ancient period. It is a compendium of medical knowledge pertaining to this non-Āyurvedic school and deals with non-mercurial metallic compounds, mercurial preparations, therapeutic actions and rejuvenating effects of such preparations and the religious faith of the *Rasacikitsā* school. *Rasasāra* and *Rasahṛdayatantra*, two important works on alchemy and mercurial preparations, are widely believed to have been written by Govinda Bhāgavata Padācārya, the preceptor of Śaṅkarācārya (ninth century), but they are very

possibly the works of another later Govinda Bhāgavata (*c.* thirteenth century) of Gujarat. The *Rasendrasārasaṃgraha* by Gopālakṛṣṇa (fourteenth century) has been a favourite book for inorganic remedies in North India and Eastern India for many centuries. The *Dhāturatnamālā* by Devadatta (fourteenth century)—a complete manuscript is available in the Palace Library, Bikaneer—describes the winning of metals from native ores and their conversion into oxides, carbonates and salts by oxidative methods and action of mineral acids. *Rasāvatāra*, a voluminous treatise by an unknown author of unknown date, and *Pārada Saṃhitā* by Niranjan Prasad Gupta (eighteenth century or earlier) are informative treatises on the mercurial faith, mercurial remedies and the Rasa school of medicine.

During the latter part of the period under review, a combination of adverse political, social and economic factors gradually undermined the reputation and usefulness of Sanskrit-based learning, and the old cultural achievements fell into disrepute. Physicians, who also had to be erudite scholars in many branches of philosophy and sciences as required by classical *Āyurveda*, seldom found satisfactory successors, for the new generations were gradually losing their mastery over the archaic phraseology of the Āyurvedic texts; apart from a working knowledge of diagnosis and drugs suitable for treatment, many of them did not have any acquaintance with the concepts and theories which formed the basis of *Āyurveda*. Replacement of existing texts by new copies which had to be laboriously done by hand had long ceased to be an economic proposition, no new works were being written and the old copies were getting scarce due to natural decay in a damp and humid climate. The very basis, on which knowledge could be standardized and passed on, was tottering. There were also no hospitals, no medical colleges, no forums of discussions and, needless to say, no research in *Āyurveda*. The noble profession gradually passed from erudite scientists into the hands of semi-ignorant people with only hearsay knowledge or knowledge gathered from an imperfect comprehension of incomplete and incorrect texts. The members of families of long lines of Āyurvedic practitioners, often foremost in education and aptitude in their society due to centuries of family tradition in a scientific profession, quickly found other and more lucrative professions. Not knowing Sanskrit they considered the manuscripts of their forefathers as useless lumber.

The long and rigorous training in theory, medicine and surgery, compulsory in classical times,[a] gave place to a few years of apprenticeship as compounder-*cum*-assistant. The new entrants to the professions were very little interested except in methods of easy cure and were psychologically inclined to follow the path of least resistance. Actual dissections on cadavers, so necessary for surgical and anatomical knowledge,[b] had been discontinued for many centuries due to changed ideas of caste purity, and surgery was avoided or relegated to barbers when absolutely unavoidable. Obstetric practice was shunned by the male physicians due to changed ideas of

[a] *CS. Vi.*, **8** and **9**; *SS. Sū.*, **2** and **4**.

[b] *SS. Sū.*, **9**.

social intercourse and was relegated to untrained and illiterate midwives with horribly insanitary and often highly harmful methods. The teachings of the classical works regarding detailed examination of bodily eliminations and applications of douches, enemas, etc., were conveniently forgotten; for social and caste considerations, as well as prudery, dictated against such methods. The painstaking methods of diagnosis found in *Āyurveda* were replaced by diagnosis on the basis of case history and feeling the patient's pulse; the equally painstaking methods of treatment often became limited to oral medication. In the latter sphere, the metallic preparations alone were reliable, as the original pharmacognosy of plant drugs had long been forgotten and rubbish offered by traders was often passed on as genuine; for genuine prescriptions were costly to collect, prepare and store. When results were disappointing, the science had to take the blame and people turned more and more to the newly imported Western science of medicine in hope of cure.

That *Āyurveda* did not completely die out in these circumstances is a great tribute to its intrinsic merit and vitality.

PRESENT CONDITION OF *ĀYURVEDA*

In spite of its glorious career both in India and outside for more than two millenniums, *Āyurveda* has fallen on evil days and evil tongues. This is, of course, mainly due to the greater importance attached to the allopathic treatment introduced in this country during the British rule in the second quarter of the nineteenth century. The people of India hailed the new system as more scientific than *Āyurveda*, as there has been no development in the latter for wellnigh thousand years, and it has failed to take advantage of the modern scientific inventions and appliances. As a consequence of this, *Āyurveda* did not enjoy the patronage of the government. While medical colleges and hospitals were established all over India during the British rule, there were no such government institutions for the Āyurvedic system until recently, though a few have been established entirely through private efforts. An attempt to place the education and practice of the *Āyurveda* as well as the *Siddha* and *Unani* systems in a proper footing was made by the Madras Government through the establishment in 1924–25 of the Government School of Indian Medicine. Shortly afterwards similar efforts were made by Bihar, the United Provinces, the Punjab, Bombay and other provincial governments. The situation has not improved very much even after the achievement of independence in 1947.

But though the Āyurvedic system has languished, it is still a living force. A large majority of Indians, specially the rural and poorer people in urban areas, take Āyurvedic medicines. It is also a happy fact that a galaxy of brilliant Vaids and Kavirājas (practitioners in *Āyurveda*), whose name and fame spread all over India, has revived the importance and popularity of the Āyurvedic system. Thus, in spite of the apathy of the

government and a section of the people, *Āyurveda* has held its ground all over India, thanks to the private patronage and financial help from Indian States.

Reference may be made to a few private Āyurvedic institutions referred to above. Gurukul Āyurveda University, Kangri, is the most famous and there are Āyurvedic colleges and *ṭols* where the pure Āyurvedic system is taught in the old orthodox style. But a new turn was given to the system of instruction towards the end of the nineteenth century by the efforts of a number of allopathic doctors who were also trained in Āyurvedic system and actually practised it. As a result, Aṣṭānga Āyurveda College with hospitals was established by Kaviraj Jaminibhusan Ray with a handsome donation and gift of land. Thereafter, the Viśvanātha Āyurveda Mahāvidyālaya, Vaidya Śāstra Pīṭha and Mahārāj Kāśimbazar Govinda Sundarī Āyurvedic College were established respectively by M. M. Kaviraj Gananath Sen, Kaviraj Syamadas Vacaspati and Kaviraj Ram Candra Mullick. It was thought fit and proper to follow a mixed syllabus, both in theory and practice, giving rise to what is known as the integrated system. It has produced a class of practitioners who use both Āyurvedic and allopathic medicines. In this way the influence of allopathy has entered into the precincts of *Āyurveda* all over the country.

Opinions differ as to the propriety and usefulness of the integrated system. It is held by some that the products of this system acquire no deep knowledge of *Āyurveda*, i.e. treatment and preparation of medicine, and, what is worse, use allopathic medicines under the disguise of *Āyurveda* without mastering the rudiments of allopathy. The mischief, they hold, is mainly due to the fact that those who administer the Medical Department, including the integrated system, are all allopathic doctors without any knowledge of *Āyurveda*.

On the other hand, it is argued by others that in the present scientific age, State recognition should not be extended to a system of medical treatment which does not take cognizance of the modern developments in our knowledge of anatomy, chemistry, biochemistry, physiology and other allied sciences, or of such 'precision' methods for probing the human malady as are offered by thermometer, stethescope, X-ray, microscope, test of blood, stool and urine, etc. The absence of surgery is also a great drawback in Āyurvedic treatment.

It is an intriguing problem of which no easy or immediate solution seems to be at hand. Nevertheless, the fact remains that Āyurvedic system is still a living one and is likely to retain its popularity among the masses and even a section of the educated classes, save for such diseases as malaria, typhoid, kala-azar, smallpox, cholera, plague, etc., for which successful specific remedies have been discovered in modern days. It is but fit and proper, therefore, that the State should take adequate steps to ensure a good training in the purely Āyurvedic system for those who seek it. The government should provide adequate resources for the improvement of teaching on purely Āyurvedic syllabus, make proper arrangements for preparation of all sorts of Āyurvedic medicines and

experiment in Āyurvedic laboratories under eminent Āyurvedic physicians, and provide for proper training in all the departments of *Āyurveda* for students having proficiency in Sanskrit, by sanctioning proper emoluments and salary for the staff, etc. Perhaps the problem of an integrated medical system, referred to above, would be easier to solve if highly efficient Āyurvedic colleges grow side by side with the existing medical colleges.

THE *UNANI TIBB* (GREEK MEDICINE) IN INDIA

M. Z. SIDDIQI

The system of the healing art known in India as the *Unani Tibb* is the same as that called 'Arabian Medicine' by the European historians and medical men. They call it 'Arabian' because they had received it through the Arabic medical writers. The Indians call it *Unani* because it is mainly based on the Greek system which was founded by Hippocrates and developed by Aristotle, Galen and other Greek writers. The Arabic medical writers, having taken it from the Greeks, developed it further in the light of Persian medical traditions and of the Indian system of medicine, modified and improved it as a result of their own observation and experience, and handed it down to the posterity. Hippocrates has been accepted as the father of Greek medicine. To him is attributed the Greek humoral theory which laid down that the living organism consisted of four humours—blood, phlegm, black bile and yellow bile. Each of them consisted of four elements—fire, water, air and earth, each of which possessed some particular quality—heat, coolness, dryness and humidity. The organism and its single parts possess these essential qualities. The essential factor in life is the natural heat, the seat of which is the left heart. It prevades the entire organism. If the humours and their elements are in proper proportions and are properly mingled, the organism enjoys perfect health, and, if it is disturbed due to internal or external causes, disease sets in. The natural heat tries to combat it. It is the duty of the physician to help the natural healing power of the organism by suitable medicine when necessary and not to supersede or impede it. The therapeutics of Hippocrates was not bound by any fixed rules. It was essentially individualistic. According to him the physician should treat the sick and not the sickness.

From the end of the seventh century, the Muslim Caliphs and their courtiers began to take active interest in Greek philosophy and science in general and in Greek medicine in particular. They collected together the masters of Greek medicine from the various parts of their dominions and Greek medical works from their own dominions as well as from foreign countries. They also invited several Indian medical men to their capital. In less than a century they got translated into Arabic most of the Greek and several of the important Indian medical works. Under their patronage

the Arabs, as well as the non-Arabs, the Muslim and the non-Muslims began serious study of these medical works from the ninth century and continued it on a wide scale for many centuries, the main centres of their activities being Baghdad, Damascus, Cairo, Cordova and various other capitals of Islamic dominions. During this period they adapted, summarized, commented upon and made certain important additions to the Greek system of medicine as a result of their own observations and experience of medical cases.

The earliest of the independent Arabic medical writers was Ali b. Rabban, who, in A.D. 850, in his book, *Firdausúl-Ḥikmat* (Paradise of Wisdom), summarized the whole system of Greek medicine as well as the Indian system of medicine on the basis of four important Indian medical works—*Caraka*, *Suśruta*, *Nidāna* and *Aṣṭāṅgahṛdaya*. After him, his student, Abu Bakr Muhammad b. Zakariyya ar-Razi (Rhazes of Medieval Europe), who died in the first quarter of the tenth century, made a thorough study of both the systems, had been in charge of many hospitals, introduced in them the system of keeping complete records of each case, and, in his methods of teaching medicine, attached great importance to practical training of its student. This method was adopted by other physicians also.

But the pride of place among the Arabic medical writers belongs to Abu 'Ali Husain b. Abdallāh b. Sīnā (Avicenna) (A.D. 980–1036). His *Qānūn* (*Canon*) was accepted as the most authoritative medical work in Europe for five centuries (twelfth-seventeenth century). And it is accepted as the greatest authority on the *Unani Tibb* in India up to the present day. He composed 99 books, some of which occupied more than 20 volumes. Sixteen of his books deal with medical subject. The most important of them is the *Canon* on medicine.

Both before and after Avicenna, a large number of medical men in the various parts of Muslim dominions produced, in Arabic or Persian, a large number of medical books according to Greek system, adapting or changing or improving its theory or practice in the light of their own experience. They anticipated the so-called modern theory of the circulation of blood as well as the germ theory. They made great strides in symptomatology, in special pathology, epidemiology, opthalmology, dietetics, toxicology and midwifery. They pointed out the connection between exophthalmos and goitre, introduced the process of bleeding for the treatment of cerebral haemorrhage and apoplexy, performed gastric lavage, used opotherapy, and could keep a patient unconscious for seven days. They invented many delicate surgical instruments, performed the amputation of the ovula and the excision of the whole tongue, removed the diseased bone from the skull and replaced it by that of a dog. They made important independent contributions to therapeutics, pharmacy and pharmaceutical techniques, and used many drugs and chemicals which were entirely unknown to the Greeks.[a]

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[a] Siddiqi, pp. xiv ff.

The Greek medicine, thus largely improved, partly modified and better systematized by the Arabic medical writers than by the Greeks, was carried to Europe during the twelfth and thirteenth centuries. The same system was brought to India by the Muslims in the eleventh century and cultivated and followed throughout the century for 800 years side by side with the Āyurvedic system. Perhaps India is the only country in which the two ancient systems of medicine are still in vogue side by side with the modern allopathic system.

The Muslim rulers of India and of its various parts were highly interested and some of them were well versed in medicine. They attracted to their capitals the best Hakims from the various parts of the Islamic dominions and reputed Vaids from different parts of India, paid them high salaries and conferred upon them high titles and also occasionally gave them large monetary grants and landed properties. They founded numerous free hospitals in various parts of the country and collected large libraries and persuaded the Hakims to develop and improve the healing art.

During the reign of 'Alauddin Khalji, there were numerous reputed Hakims and Vaids in Delhi whose names are mentioned by Barani. Muhammad b. Tughlaq was well versed in *Unani Tibb* and personally examined and treated the patients, and discussed medical problems with the Hakims. At his persuasion Hakim Diya Muhammad, the son of Muhammad Masud, compiled in A.D. 1320 a book, *Majmuai-Diyaiyya*, on the basis of Arabic, Persian and also some Āyurvedic medical works. In this book there is reference to another book, *Majmuai-Shamaiyya*, which was compiled earlier by Shamsuddin Mustaufi, which is said to be a Persian translation of an Āyurvedic book.[a] Firoz Shah Tughlaq had a thorough knowledge of *Unani Tibb*. He had dictated a book, *Tibbe-Firoz shahi*, on the subject and personally attended to the patients in a large free hospital founded by himself. He was a good bone-setter and was specially interested in opthalmology. Mian Bhowa, the Lord Chamberlain of Sikandar Lodi, collected together numerous competent Hakims and Vaids and got compiled by them, an Indian treatise of medicine, on the basis of a dozen of important Āyurvedic works. This book is known as *Ma'danush-Shifâi-Sikandari*. Mian Ṭaha, another Amir of Sikandar Lodi, according to a contemporary historian, was well versed not only in Islamic literature and Indian music and arts and crafts, but also in Indian system of medicine. He remembered by heart twenty-four thousand verses on Indian medicine; and Hindu experts in Indian medicine and music took lessons from him in these subjects.[b]

The provincial Muslim rulers of the various parts of India followed the footsteps of the Sultans of Delhi and encouraged their court physicians to develop medical literature. Thus, during the reign of Muzaffar Shah of Gujarat (A.D. 1396–1410), Hakim Shahabuddin compiled two books on medicine: (1) *Tibbi-Shifaul-Khani* in Persian prose and (2) *Tibbe-Shihabi*

[a] *Hamdardi-Ṣiḥḥat*, pp. 4–9.

[b] Siddiqi, pp. xxxii ff.

in Persian poetry. He compiled these books on the basis of Arabic, Persian and some Āyurvedic works and took help in this connection from some Yogis. He has mentioned in the book the names of certain drugs in Sanskrit as well as in Sindhi. After him Hakim 'Ali Muhammad, the court physician of Mahmud Shah (A.D. 1458–1510),[a] translated at his command, with the help of some Pundits, a book of Vāgbhaṭa from Sanskrit into Persian.[b]

In the Deccan under the Bahmanid ruler, Mahmud Shah (A.D. 1378–1396), translated certain Āyurvedic works into Persian, in three volumes. It was named *Tibbe-Shifai-Mahmudi.*[c] Under the 'Adil-Shahi dynasty of Bijapur, Hakim Muhammad Qasim Hindu Shah, generally known as Firishta, wrote in the year A.D. 1590 a book, *Dasturil-Atbba*, which is also called *Ikhtiyarati-Qasimi.* In the introduction to this book, he says that at first he made a deep study of the *Tibbe-Unani* and after that he studied Āyurvedic system of medicine also, and found its theories as well as its practice well founded though at the outset they appeared to be strange. He adds that he was also closely associated with some of the Vaids. To several of them he was referred by name.[d] Alauddin Ahmad Shah II of Bahmani dynasty founded a large free hospital at Bidar, appointed Hakims as well as Vaids in it to attend to the patients. He also established a medical school which was attached to the hospital. In his court there were numerous Hakims and Vaids, some of whom[e] compiled some important medical books. As a matter of fact, since the advent of the Muslims, the Deccan has ever been one of the important centres of the *Unani Tibb.*

Like Gujarat and the Deccan, the rulers of each of the local Indian Muslim State had in their courts several Hakims and Vaids, some of whom made their own contributions to the development of the *Unani Tibbi* literature in India.

The advent of the Mughals added largely to the popularity, progress and glory of *Unani Tibb* in India. They gave the Hakims much higher position and paid them much higher salaries, giving some of them Rs.50,000 per annum, and occasionally bestowed upon them much higher rewards in cash and in kind that did their predecessors. Thus they attracted to India many more highly qualified Hakims from Iran and other places than their predecessors could, and encouraged them to cultivate and advance the *Tibbi-Unani* in this country. They also established a network of many new free public hospitals in all the large cities of the country.[f]

These hospitals must have been organized according to the same principles as those of the other Islamic dominions which, according to Cyril Elgood,[g] were as models of the European hospitals. But in the medieval Indian hospitals generally the Hakims and the Vaids worked side by side as it is obvious from the description of the hospital which was founded by a Khayr Andish Khan given in his *Khayrut-Tajarib.*[h]

[a] *Hamdardi-Ṣiḥḥat*, pp. 4–9.
[b] *Ma'ārif*, pp. 35–42.
[c] *Islamic Tibb*, pp. 127–33.
[d] Siddiqi, pp. 109 ff.
[e] Siddiqi, pp. xxxv–xxxvi.
[f] Siddiqi, p. xxxv ff.
[g] Elgood, p. 178.
[h] Siddiqi, p. xxxvi.

Abul-Fazl has given the names of 39 Hakims of his time in his *'Ain*. But they were only those who were in the service of the court at Delhi. In the whole country the number of the Hakims who either served in the various hospitals or carried on private practice in the various parts of India, during the Mughal rule, must have been several thousands. The main centres of their medical activities were Lahore, Delhi, Lucknow, Patna, Murshidabad, Hyderabad, Madras and other important towns. In many of these centres there were not only well-equipped *Unani* hospitals, but also *Tibb Mādrasas*.

These Hakims made large contributions to the so-called *Tibbi-Unani*. A large part of this literature consisted of the translation, commentaries or summaries of Arabic medical books, or of the translation or adaptation of Āyurvedic works. And some of them are based on any one or both of them. The *Tibbi-Aurangzebi*, which was dedicated to Aurangzeb, is entirely based on Āyurvedic sources. The *Mu'aálajáti-Darshikohi* of Nuruddin Muhammad, which was dedicated to Darasdhikoh, is based mainly on the Greek system, but contains at the end almost the whole of Āyurvedic *materia medica*.

But it would be a mistake to suppose that the Indian Hakims made no independent contribution to the so-called *Tibbi-Unani*. The author of the *Khulastu't-Tajárib*, after summarizing the Greek theories mainly according to Avicenna, described a large number of diseases and their treatment, gave clinical description of many cases and mentioned the medicaments according to the Greek as well as the Āyurvedic system. He laid it down that in the science of medicine experience is the basic principle of treatment. He described several diseases including whooping cough which were not recognized in Europe for centuries after him. He has referred to Greek authors but very seldom to Āyurvedic works. Hakim Sharif Khan (A.D. 1725–1806) in his *Tálifi-Sharifi* collected together the names of such Indian drugs as he had tried and found useful. In his *Tuḥfa-'Alam Sháhi* he has discussed the properties of various Indian diets and has remarked that a patient may be easily cured by the use of proper diets only.

As a matter of fact, Hakims of the various parts of India, during the different periods, produced a large number of books on the various branches of medical science on the basis of *Unani* or Āyurvedic system of medicine and on the basis of their own experience of medical cases.

The last large and more or less exhaustive book, the *Iksiri-A'ẓam*, on the various diseases from head to foot, their causes, their diagnosis and their treatment according to the Greek system, was compiled by Hakim Muhammad A'zam Khan, in four big volumes on the basis of most of the important medical works on the *Unani Tibb* in Arabic or Persian, written in or outside India. The book, in spite of its large size, has already undergone four editions.

The author has never referred to any Āyurvedic work. But he has often mentioned the Indian medicaments after dealing with the treatment of the various diseases. He also compiled another large book, The *Muḥiṭi*

A'ẓam, on *materia medica*, on the basis of 68 previous works on the subject. In it, he has mentioned a large number of Indian medicaments belonging to vegetable, mineral and animal kingdoms. These books contain the summary of all the previous works on these subjects.

The Hakims generally thought that the basic Greek theory of medicine, which was supported by Arabic medical writers also, was unassailable. But a reaction against this attitude began in the nineteenth century, due to the influence of modern scientific discoveries and the allopathic system of medicine. In A.H. 1295 (A.D. 1878), Hakim Afḍal 'Ali of Faydabad wrote a book, *Jami 'ush-Shifaiya*, in which he strongly challenged the theories of the Greek system and remarked that most of it was based on wrong presumptions. After him, Masihu'l-Mulk Hakim Muhammad Ajmal Khan, a man of versatile genius, broad outlook and wide influence, realized the defects of the *Unani* system of medicine, and tried to reform it in every possible way. He founded the Āyurvedic and the Unani Tibbi College in Delhi, reformed its courses of study and established a strong department of research on Indian drugs. He also fought hard against the aggressive attitude of the Medical Council and the British Government against the indigenous systems of medicine. He was helped in his efforts by the transfer of the Education Department to Indian Ministers, who, after making the necessary enquiries about the popularity and the practical utility of these systems, decided to establish official teaching institutions and hospitals for them. Thus were established, in addition to the already existing public Tibbi teaching institutions, official Tibbi colleges also at various places.

The institution for research in *Unani Tibbi*, founded by Hakim Ajmal Khan, came to an end after his death. But its noble object was taken up by the Hamdard Dawakhana of Hakim Abdu'l-Hamid of Delhi, who established the Institute of History of Medicine and Medical Research with a hospital, a herbarium, medical library and a well-staffed department to do research according to modern scientific system, on the history of medicine in general and on the *Unani Tibbi* medicaments in particular, and endowed upon it a very large part of the income of the Hamdard Dawakhana.

The Indian Hakims, however, made a large contribution to Persian medical literature, discovered new diseases and their treatments, developed the treatment of the veneral diseases and made fresh contribution to epidemiology, toxicology, therapeutics and *Unani Materia Medica.* They served sincerely the ailing Indians, the rich as well as the poor, during the last 800 years. And they are holding high the flag of *Unani Tibb* in India at present also.

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5 CHEMICAL PRACTICES AND ALCHEMY

B. V. SUBBARAYAPPA

CHEMISTRY as a branch of modern science is admittedly not very old; for, to be precise, it became systematized only in the latter half of the eighteenth century A.D. mainly because of experimentation and the methodical interpretation of experimental results by Lavoiser (1743–94) and his contemporaries like Joseph Black (1728–99), Henry Cavendish (1731–1810), Joseph Priestley (1733–1804) and Carl Wilhelm Scheele (1742–86). As a candid recognition of our indebtedness to the past, it must be said that chemical practices have been very ancient, and they formed an integral part of the technical skills of antiquity. The practical chemists—potters, brewers, dyers, metalsmiths, glassmakers and the like—contributed a great deal to the growth of technology and in no small measure to the economic welfare of the ancient communities. They were noted for their craftsmanship and experimental skills involving many a chemical transformation both qualitative and quantitative, even though they did not appear to have formulated any theoretical knowledge of the chemical transformations. For example, the beginnings of modern chemical processes, such as fermentation, distillation, fusion and calcination, can be traced to very ancient times despite the fact that the scientifically valid theoretical principles governing them came to be understood only a century or two ago.

Similar is the case with the use of chemicals when man became the food-producer, and began to lead a settled life. There is no doubt that as man became more and more civilized, he developed varied avenues for the use of a number of chemicals and, in the process, acquired considerable knowledge of their occurrence, preparation and properties even though that knowledge, in point of fact, was not deep and systematized from the point of view of modern chemistry.

In India, the beginnings of chemistry as practical and purposeful art are noticeable in remote antiquity. Of particular importance is the knowledge as well as the technique concerning the baking of clay and production of pottery, i.e. of objects fashioned from clay and hardened by fire. The use of pottery has an added significance in the history of chemistry. For, besides satisfying the potter's urge to create forms and paint artistically on

them, the use of pottery enabled the ancient practical chemists to develop processes involving prolonged heating, fusion, evaporation and, more importantly, the treatment of minerals. India has been well known for a number of pottery types from the neolithic phase right up to the medieval period. Metal-working, processing of various naturally occurring minerals, slaking of the burnt limestone, compositions of mortar and cement, preparation of fermented juices, extraction of essential oils, use of pigments, and production of different types of glass were among the noteworthy chemical practices in India even in very ancient times. Though it is rather difficult to trace the indigenous origins of these practices, there is no doubt that most of them grew out of the sustained efforts and special technical abilities of the people of the region, and reached peaks of excellence at times.

PRE-VEDIC PERIOD (FROM PREHISTORIC TIMES TO *c.* 1500 B.C.)

Pottery

There is evidence to indicate that in the prehistoric period the technique of pottery-making was known in India. It would appear that the pots were hand-made in that period, the potter's wheel being unknown. There were also no kilns specially built for firing the pots. Heating was done by raising a small fire around the pots which were placed in circular pits after covering the pots partially with sherds. The common shapes were globular pots of various sizes with round bases and flaring slips. Bowls with several shapes of bases were also in use. Hand-made, coarse and ill-fired redware sherds with microliths have been found in the excavations (late levels) of the prehistoric rock shelters at Lekhahia (Mirzapur district in Uttar Pradesh), and also in Baluchistan, Mundigak, Langhnaj (north Gujarat), Nagarjunakonda (Andhra Pradesh) and Birbhanpur (West Bengal).[a] Hand-modelled pottery, coarse grey or black burnished and ill-fired, with mat-marked bases has been noticed at Burzahom (Kashmir; about ten miles north-east of Srinagar) in the early neolithic phase (*c.* 2375–1500 B.C.). In the southern Deccan (e.g. Brahmagiri, Sanganakallu, Utnur, Piklihal, Paiyampalli and T. Narasipur) hand-made grey or buff-brown pottery (some having black or red burnished slip) with ring feet and hollow pedestals, and bands of red ochre on the surface, have been found (*c.* 2300–1800 B.C.). The wheel-thrown ware also appeared soon in this region as evidenced by the Black-and-Red painted pottery.[b]

In the history of the wheel-turned pottery, as also of other chemical practices in India, special significance attaches to the Indus Valley Civilization

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[a] Rao (S. R.) (1), p. 20; *IAR*, 1959–60, pp. 5–10.

[b] Thapar (3), pp. 87–92; Wheeler (1), pp. 222 ff.; Subbarao (2), pp. 48, 117, 175–76.

which was by far the largest of the world's three most ancient civilizations. This great civilization, now referred to as the Harappa Culture, is known to have flourished during the period *c.* 2300–1750 B.C. and its sites have been located in the Panjab, Haryana, western Uttar Pradesh, north Rajasthan (former State of Bikaner), Kutch, Saurashtra, central and southern Gujarat, and Baluchistan, covering an area of roughly 840,000 square miles.[a]

In the early occupations at Harappa and other regions, generally designated as the pre-Harappan culture (*c.* 2600–2400 B.C.), wheel-made pots with red wash and black paintings have been found, as also of polychrome styles. The pottery of the pre-Harappan occupation at Kalibangan, a site on the now dried up Ghaggar river in the district of Ganganagar in Rajasthan, is light and thin in fabric, even though the sturdy fabric with incised designs is not wanting. The colour of this pottery is red to pinkish, painted in black, sometimes with white painting over half-slipped dull surface. On the basis of the fabric and decoration, this pottery, which presents a number of motifs, has been classified into six groups—labelled Fabric A to Fabric F.[b]

The pottery of the Harappan culture which consists of mainly wheel-made ware, turned in various shapes and sizes out of the well-levigated alluvium of the Indus, comprises the Red, Buff, Black-and-Red, Coarse Grey and the Micaceous Red ware with paintings in black over red.[c] The colour and the other characteristics of these wares depended obviously upon the composition of the clay used and the techniques of firing under either oxidizing or reducing conditions. Mica, sand and lime were used as tempering materials. The presence of mica in the clay generally helped not only in the working of the pot on the wheel but also in the process of drying of the pottery without cracking. The red shades which developed on the pottery were due to the presence of iron compounds in the clay, which would undergo change in colour in the course of firing as a result of the oxidizing atmosphere in the kiln. Not infrequently the black or chocolate designs painted on the body of the ware were executed using manganiferous haematite compositions. However, the exact information respecting the techniques employed for obtaining the distinctively coloured pottery still appears to be scanty. Decoration of pottery often consisted of several designs, geometrical, plant or animal forms fashioned normally in black paint. The designs included, among others, squares divided into a number of triangles and rectangles, wavy lines, loops, chequers, lattice work, rosettes, forms of peacock, flying birds, deer and fish, *pipal* and palm leaves, and occasionally human forms. The potters were indeed skilled craftsmen of high order as evidenced by the exquisitely executed miniature vessels. 'The general impression given by the Indus pottery is that of efficient mass production',[d] and what is remarkable is the extreme standardization of production.

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[a] Sankalia (4), p. 155.
[b] *IAR*, 1962–63, pp. 20–27.
[c] Rao (S. R.) (1), p. 21.
[d] Wheeler (4), p. 52.

The white ash remains of the kilns point out unmistakably that wood or charcoal was used as a source of fuel. At Harappa have been found three types of furnaces, viz. round, cylindrical and pear-shaped pits, with

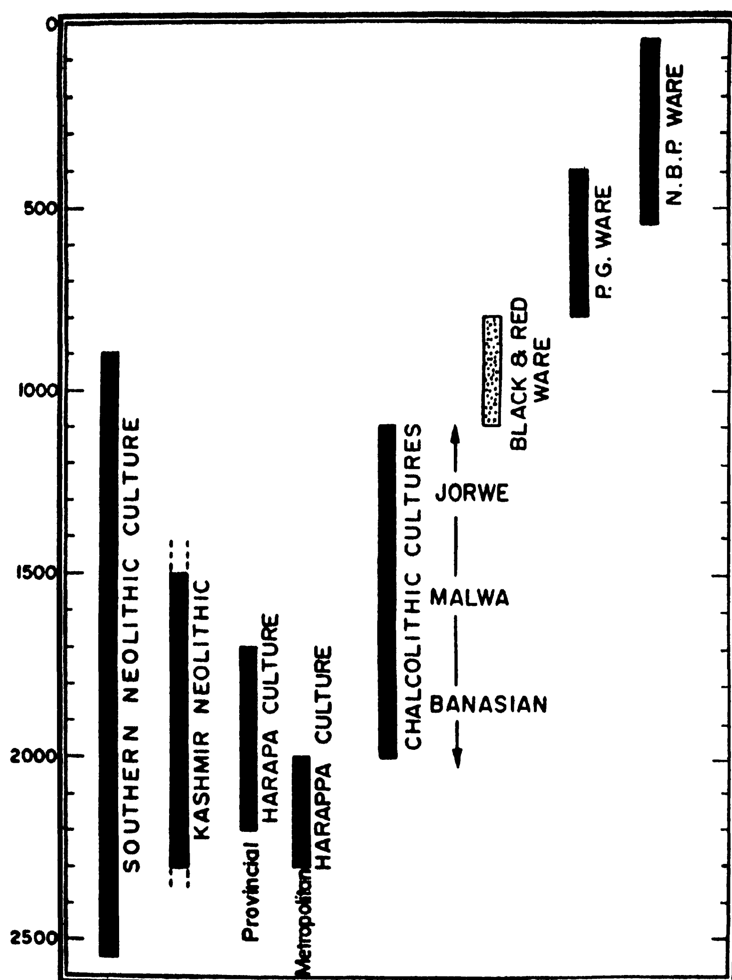


Fig. 5.1. Bar-diagram showing the chronological spread of different cultures and wares.[a]

or without brick-lining. The art of glazing the pottery was also known. In the production of the glaze on the surface, gums and allied organic substances were used along with the glazing materials which consisted of finely

[a] Agrawal (D. P.) (2), p. 116. (Reproduced with permission).

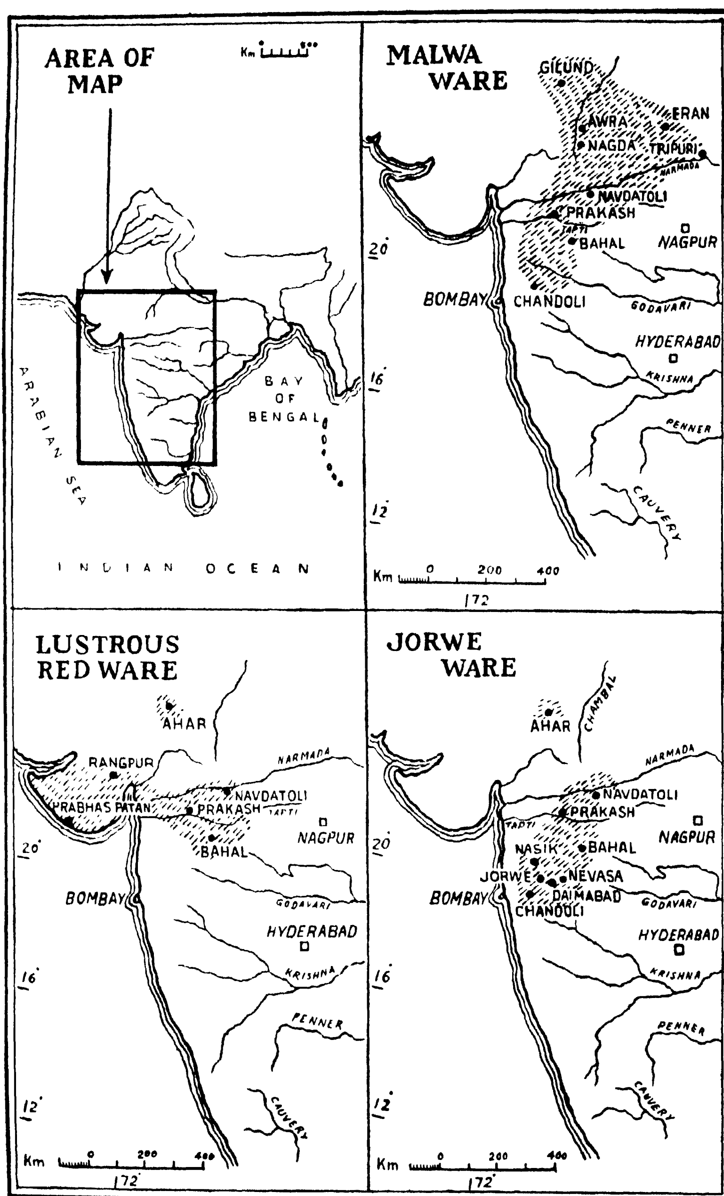


FIG. 5.2. Map showing the spread of Malwa, Jorwe and Lustrous Red wares.[a]

[a] Thapar (2), p. 36.

crushed quartz or white sand, a glassy flux (probably obtained by fusing soda with sand) and, if desired, a colouring matter. An analysis of a few specimens of glazed pottery has revealed that the blue shades are due to copper oxide, the greenish blue due to iron oxide in addition, while excess of manganese oxide is responsible for the appearance of dark or maroon colour. Mackay is of the view that the glazed pottery found at Mohenjo-daro was probably the earliest specimen, and according to him the four pieces found at Mohenjo-daro are beyond all doubt the handiwork of a potter who was well acquainted with the process and able to carry it to a high degree of perfection.[a] It is known now that the practice of glazing the pottery appeared in Mesopotamia about 1,500 years later than in the Harappan culture.

The terracotta craft, another aspect of pottery-making, which included the execution of human and animal forms, dolls and other decorative pieces, was in practice in the Harappan culture. The Harappan figurines, entirely hand-modelled, which have been unearthed speak of the achievements in the terracotta craft.

A detailed enumeration of the pottery of the post-Harappan cultures of the north, the north-west, central and southern India is not possible in this short account. Suffice it to say that there was a continuity in the potting tradition though some of the Harappan features disappeared and some new decorative motifs appeared. In course of time, there came into use the bright red burnished ware known as the Lustrous Red ware found in sites in Kathiawar and western India. Black-and-Red pottery often with white painted geometrical designs also made its appearance. This type of pottery dominated in what is known as Ahar culture (also called the Banas culture named after the river Banas in the south-eastern Rajasthan (*c.* 2000–1600 B.C.). Cream-slipped ware with remarkable surface paintings and the red-slipped ware also belong to the Banas culture. Besides, during the period under reference the other important pottery assemblages comprise the Malwa ware (Navdatoli, Prakash, Bahal, Eran, Nagda, etc.; its distribution covers the basins of Chambal, Narmada, Tapti and Godavari rivers) which is generally a pale-red-slipped ware decorated with designs painted in purplish to brown-black colour; and the Jorwe ware (Jorwe, Nasik, Nevasa, Daimabad, Chandoli, etc., in the northern Deccan) which has a well-baked core with a metallic ring and a light orange or dull-red matt surface having geometrical paintings in black colour.[b, c]

Metals and Metal-working

In the field of metals, the pre-Harappan cultures are not noted for an extensive use of metals by them; only at a few places (Mundigak, Nal, Kalibangan and Mehi), there is evidence of the use of copper. But the picture

[a] Mackay, p. 188.
[b] Sankalia (4), pp. 199–200.
[c] Thapar (3), pp. 25 ff.; *IAR*, 1954–55; 1955–56; 1957–58; 1958–59.

is entirely different in the Harappan culture, the metal-workers of which undoubtedly knew the art of using copper, bronze, lead, silver, gold and electrum—an alloy of gold and silver. Silver might have been obtained from Afghanistan, Armenia and Persia, copper ore from Rajasthan and Afghanistan, and lead from Ajmer area. The Harappan metalsmiths were well aware of the technique of making beads, soldering, sheet-making, rivetting, coiling and *cire perdue* casting (lost-wax metal-casting process, the details of which are given elsewhere in this chapter). Gold was used principally for making ornaments (beads, pendants, armlets, brooches, etc.) and silver for ornaments, vessels and the seals. 'Much of the Indus gold is of light colour, indicating a high silver content, or rather that it is unrefined "electrum". This suggests that it originated from the reefs of Mysore rather than from panning, and the possibility is certainly not discouraged by the numbers of neolithic settlements which are reported from Mysore, particularly clustering around the Hatti gold bands.'[a, b] Copper sheets were shaped into vessels, and bronze was used for casting purposes by the *cire perdue* process. It is generally believed that the small bronze statuette of the 'dancing girl' discovered at Mohenjo-daro was fashioned by casting, probably by the lost-wax process, although there is no direct evidence to this effect as yet.[c] Moulds for casting bronze have not been found yet in the excavations at Mohenjo-daro. This bronze statuette seems to represent the first appearance of the figure in the metal-art of India.

The specimens unearthed at Mohenjo-daro, of copper-bronze implements or tools and weapons of warfare include axes, daggers, knives, spears, arrow-heads, short swords, chisels, drills, reamers, fish-hooks and metal mirrors. About 70 per cent of the tools excavated are found to be unalloyed as they have in them about one per cent of tin only, while only 14 per cent of them are alloyed correctly (8–12% tin). It would thus appear that the Harappan metalsmiths were not able to maintain the correct proportions of tin while alloying and producing implements on a large scale.[d] A remarkable metallic tool, though rare, of Harappan culture is the true saw which has the teeth and the adjoining part of the blade set alternatively from side to side. It would seem that this type of arrangement in a saw was unknown elsewhere until the Roman times. According to Mackay, no metal arrow-heads of the type found at Mohenjo-daro have as yet appeared in Egypt, nor in any Sumerian or Elamite sites. Identical arrow-heads, however, were in use at Minoan and Mycenean sites at a later date.[e]

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[a] Allchin (B. and R.), p. 284.

[b] Rao (S. R.), in his Presidential Address to the Conference on Keladi Dynasty, Shimoga, 1969, refers to a large number of neolithic sites near Kolar gold mines also.

[c] Reeves, pp. 19–20.

[d] Agrawal (D. P.) (2), p. 174; according to Rao (S. R.) the Harappans knew well how to mix tin with pure copper in the proportion they desired for making ornaments. As a peace-loving people, they were not anxious to produce bronze weapons (personal communication).

[e] Mackay, p. 461.

Though copper and bronze were in common use, there are indications that an alloy of copper and arsenic (3–4·5%) was also used in the place of low grade bronze. The Harappan metalsmiths appeared to have a sound knowledge of cold-working and the annealing of metal. Evidently they used crude copper (with considerable sulphur content) for casting plain objects, and refined copper for shaping it into the desired types of vessels. Possibly the vessels were shaped, raised or sunken by hammering. Not unoften open moulds were used for casting purposes. A number of bun-shaped ingots and castings have been found on the sites of Mohenjo-daro and Lothal, and it is not unlikely that the copper ingots (99·46–99·8% pure) which have been found at the latter site were imported from outside, possibly from Mesopotamia. Obviously, smelting operations utilizing the ores were carried out in the neighbourhood of mines and, as Mackay says, the rough 'metals' were transported and made available to the workers for refining and subsequent workings. Though the kilns used for these purposes have yet to be found, Mackay[a] is of the opinion that the ore (possibly with alternate layers of charcoal) was smelted in an open hearth, using charcoal as fuel over a cavity in the ground so that the molten metal would run into the cavity. There is no denying the fact that, in comparison with the other chalcolithic cultures at Ahar, Navdatoli, Chandoli, Nevasa, Jorwe, etc., where a number of copper objects like chisels, bangles and fish-hooks have been found, the Harappan culture was far advanced in the technique of metal-working. This was probably due to the special attention bestowed on the durability, utility and elegance of the metallic tools and implements. However, a fact of special significance is that the metallurgy of iron was unknown to the Harappan metal-workers.

While considering the metal-working and metallurgical practices in the pre-Vedic period, a reference to what is termed as 'copper-hoards' is necessary. These copper artifacts, about a thousand in number and many of them found in hoards (hence the name), have been reported from some 34 sites in Uttar Pradesh, Central India, Bihar, Bengal, Orissa and Andhra Pradesh. The types of copper-hoards include flat axes, shouldered axes, bar-celts, or chisels, harpoon-heads, spearheads, rings, antennae swords and anthropomorphic objects.[b] The tools, which might have been fashioned by closed casting, are largely of copper and hence the knowledge of alloying might have been unknown to their makers who were probably semi-nomadic metalsmiths. Although the chronological problem relating to the copper-hoards has not been solved satisfactorily yet, their probable date may be *c.* 1700–1000 B.C. There is a view associating the copper-hoards with some pre-Aryan tribal people who inhabited the Ganga basin.[c, d] A striking feature of the problem of these hoards is that none of them has been found in stratified deposits, nor has any pottery been found so far in direct association with them, although the Ochre-Coloured ware has been noticed

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[a] Mackay, p. 451.
[b] Wheeler (2), pp. 119–24.
[c] Lal (B. B.) (1), pp. 20 ff.
[d] Gupta (S. P.), pp. 147–66.

in the later excavations at the four copper-hoards sites, viz. Bahadarabad, Bisauli, Safai and Rajpur Parsu. A close examination of the tool types indicates their unique character.

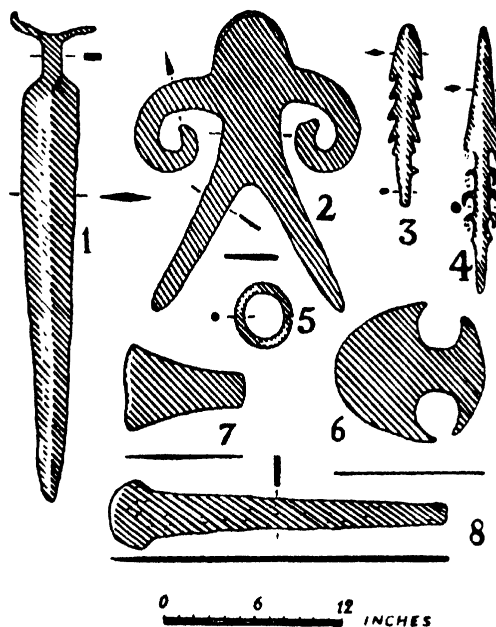


FIG. 5.3. Copper-hoards: some implements and other objects from the Gangetic region.[a] 1, antennae sword from Fategarh; 2, 'anthropomorph' from Shivarajpur; 3–4, harpoons from Sarthauli and Bisauli; 5, ring from Pandi; 6, double axe from Bhagra Pir; 7, axe from Gungeria; and 8, bar-celt from Gungeria.

Other Chemical Practices

Extensive archaeological excavations in different sites of the Indus valley have brought to light more details relating to the chemical knowledge and technological practices as far back as about 4,500 years. It would appear that both gypsum and lime were used as plaster materials at Mohenjo-daro and Harappa. Chemical analyses of the samples collected from different places at Mohenjo-daro indicate that mortars were generally made of gypsum, lime and sand. Burnt brick (well-cut, colour ranging from that of straw to bright red) made from ordinary alluvial soil found use in the extensive construction of walls, bathing-pools, drains, wells, etc.

The remains unearthed at Mohenjo-daro and Harappa reveal that the people of the Indus valley were using a variety of minerals for ornamental,

[a] Wheeler (2), p. 119; Lal (B. B.) (1), pp. 20 ff.

cosmetic and medicinal purposes. Lapis lazuli (beautiful blue stone, principally silicate, stained deep blue by the presence of other minerals), turquoise (hydrous phosphates of aluminium and copper used as a gem), alabaster (pleasing form of stained gypsum or hydrated calcium sulphate used for ornamentation), haematite (ferric oxide), jasper (impure opaque silica), amethyst (either quartz or aluminium oxide used as a semi-precious stone) and agate (crystalline coloured variety of silica) are among a number of mineral objects found in different sites of the Harappan culture. Obviously, the Harappan artisans must have had an intimate knowledge of the processing and properties of these naturally occurring chemical substances. A close examination of the finds indicates that the Harappan craftsmen had developed to a high degree the art of shaping as well as polishing the precious and semi-precious stones which were used generally for the production of beads with great dexterity.

While the remarkable achievements of the Harappan people in the practical chemical arts of pottery, metal-working, use of minerals and the like have come to light, there is little or no information about the speculations or conceptual frame of the people relating to their achievements. Even not much is known of the people of this great civilization. The Harappans had developed a script which has been characterized partially as 'pictographic'.[a] So far about 400 distinct signs have been observed and the script is not found to be alphabetic. The letters on the inscribed sherds found at Kalibangan indicate that the direction of writing was from right to left. The script has yet to be deciphered on a rational basis, and only its decipherment would throw light on the thoughts and practices of the Indus valley people; it may also unfold the origin and evolution of these people in a way more authentic than what is presently known.

THE VEDIC AGE

In the next phase of the early Indian cultural history (*c.* 1500–600 B.C.) we have to consider the chemical knowledge and practices of a new set of people with a new social order, often referred to as the Indo-Aryans who are believed to have settled first in north-western India and gradually extended their settlements over the whole of north India. The probable date of this presumed Indo-Aryan cultural settlement has not been settled yet beyond doubt. Till recently, the chronological range of the Harappan culture was recognized to be *c.* 2500–1500 B.C., while the radiocarbon analysis[b] of the charcoal remains of this culture-area, points to a date

[a] Majumdar (R. C.), I, p. 181.

[b] Carbon-14 (C^{14}) is a radioactive isotope of carbon (or radiocarbon) with an atomic weight of 14, the normal atomic weight of carbon being 12. The radiocarbon is being produced in nature as a result of the interaction of the fast-moving neutrons (which are themselves produced from primary cosmic rays on entering the earth's atmosphere) on N^{14} atoms of the air. The radiocarbon combines with oxygen forming

range of *c.* 2300–1750 B.C.[a] Again the radiocarbon-dating methods have indicated that the distinctive type of pottery known as the Painted Grey ware, which is believed generally to have been used by the Indo-Aryans, might have been evolved by them around *c.* 1000–800 B.C. The old conception that the Aryans might have destroyed the Harappans is gradually losing ground as a result of recent studies; instead, the possibility of flood as also the shifting of courses of ancient rivers, annihilating the flourishing Harappan civilization is increasingly acquiring credence.

Whatever may be the Aryan problem in India—and a discussion on this is beyond the scope of the present account—it would seem that the Aryans, in course of time, might have mixed with the non-Aryans or the early inhabitants, assimilating or giving a new dimension to the cultural, conceptual as well as utilitarian practices of the latter. They followed the sacred hymns, rituals and thoughts which went under the names of the *Vedas*, the *Brāhmaṇas*, the *Āraṇyakas* and the *Upaniṣads*, some of which give a glimpse of a few chemical practices prevalent then.

The *Ṛgveda Saṃhitā*, the earliest literary composition of this period, mentions the use of metals including gold.[b] Even though in this text there does not seem to be any plausible account of the metallurgical practices followed by the people of that time, possibly the ore was smelted in small furnaces. The general term used for the metal is *ayas* which might have meant copper, bronze or lead. There is no doubt that later the word *ayas* began to mean iron.[c] The Vedic people believed that gold possessed

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gaseous carbondioxide ($C^{14}O_2$) and the latter gets into the vegetation as a result of plant metabolism and also into the animals which feed on vegetation.

When carbon-14 disintegrates, nitrogen is formed and beta particle is emitted. In 5570±40 years, known as the half-life period of carbon-14, half of a given number of atoms of the radiocarbon undergoes radioactive decay and, with the lapse of time, the radioactivity goes on decreasing. It has been calculated that in about 70,000 years, practically all its radioactivity will be lost. The quantity of radiocarbon in contemporary materials is too small and far below the sensitivity limit of an isotope-measurement device such as the mass spectrograph. However, its radioactivity can be measured and, by comparing the radioactivity of a particular carbon remnant (like plant remains, charcoal, marine shells and carbonate deposits) with that of carbon of the present time, the time elapsed in relation to the carbon remnant can be arrived at mathematically.

It is generally assumed that all living organisms possess the same proportion of carbon-14/carbon-12 and that the radiocarbon disintegrates at the same rate after their death. These assumptions are not found to be strictly correct and hence a certain amount of error creeps in the reckoning of dates by the radiocarbon method.

(For details *see* McGraw-Hill Encyclopedia of Science and Technology, 1960, Vol. II, pp. 291–96).

[a] The earliest levels of Mohenjo-daro and Lothal for which no carbon-14 dates are available are presumed to go back to 2500–2400 B.C. (Rao, S. R., in a personal communication).

[b] *ṚV.*, I. 85.9, 88.5, 167.3; II. 33.9; V. 54.15, 57.1, 60.4; VIII. 7.27–32, etc. Generally gold and silver plates found use at sacrificial rites. Silver was also referred to as white gold.

[c] On the basis of the available archaeological evidence a view is coming to the fore that iron was introduced into India by about 1000–800 B.C.

supernatural powers (a general belief common to all people of the ancient times). The *Atharvaveda* even speaks of gold as conferring long life on one who wears it.[a] The metal-workers of the Vedic period doubtless possessed the technical knowledge of using copper and bronze for the production of utilitarian appliances for domestic as well as ritual purposes.

The Vedic people were well aware of the fermented drinks and the methods of fermentation. *Soma* juice,[b] as the divine drink of immortality, finds an honoured place in the *Ṛgveda Saṃhitā*. It was obtained by pounding the shoots or stalk of the *soma* plant (*Sarcostema viminalis*) between stones (*adri*) to obtain the juice. The pressed juice was passed through a filter comprising sheep's wool to get a clear juice which was then blended with milk, sour milk or barley. The exhilarating powers of the *soma rasa*, as the juice was called, have been described elaborately in the *Ṛgveda*. It was even called *amṛta* (ambrosia) and, no wonder, the *soma* plant was extolled as being divine. There were also two other fermented liquors in use, viz. *madhu* (a kind of fermented liquor taken as drink during feasts) and *surā* (probably a type of beer brewed using barley grains).

Pottery

The Indo-Aryans, according to some scholars, seem to have developed and used a type of pottery now designated by the archaeologists as the Painted Grey ware (P.G. ware).[c] A fact that merits attention is that P.G. ware even at its earliest occurrence in India is of a fully developed type. As some similar ceramic ware has been found outside India in parts of Greece, Iran and Siestan probably dating back to second millennium B.C., it is possible that the settlers on the plains of the Ganga and the Yamuna had a knowledge of this type of ceramic and, utilizing the then existing local ceramic techniques, might have developed the appropriate baking conditions for the production of the P.G. ware. This ceramic, the approximate date range of which is *c.* 1000–400 B.C., is a thin grey *deluxe* ware and mostly wheel made, well burnt, glossy and copiously painted. The decorative motifs on this pottery include bands, criss-cross lines, dots and dashes, circles and swastikas. Generally, the pottery shapes comprise carinated bowls, cups and dishes.[d] The archaeological evidence indicates, by and large, an extensive western distribution of the P.G. ware (which was first noticed at Ahicchatra) in the valley of the Sarasvati or the modern Ghaggar and also the Gangetic plains. Apart from the Painted Grey ware some other types of pottery like Coarse-Red ware, Fire-Red ware, Plain-Grey ware were also in use then. Later came into use probably in

[a] *AV.*, XIX. 26.

[b] *See* IX *maṇḍala* of *ṚV.*; also VIII. 48; I. 85.10; II. 12.14. The offering of *soma* (the Avestan *haoma*) was an important feature of the Indo-Iranian rites.

[c] A pottery, which precedes the P.G. ware and which has been found at Hastinapur, Ahicchatra and Atranjikheda, is known as Ochre-Coloured ware.

[d] Sankalia (4), pp. 182–86; Wheeler, pp. 98 ff.

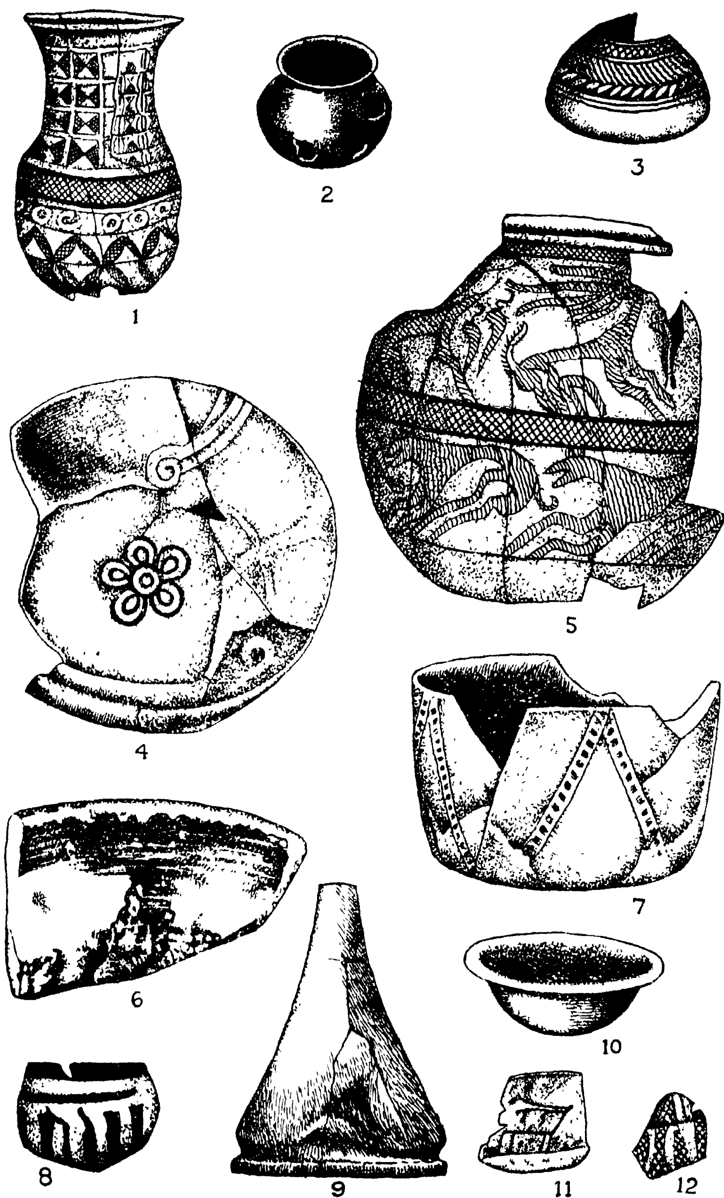


FIG. 5.4. Sketches of some pottery types: 1, Harappan pottery (Lothal);[a] 2, Black-and-Red ware (Ahar);[b] 3, Malwa ware (Navdatoli);[c] 4 and 7, Painted Grey ware: dish (Ahicchatra) and bowl (Panipat);[d] 5, Jorwe ware: white stipped pot with designs of elongated and hatched bodies of animals;[e] 6 and 8, Northern Black Polished ware: painted and incised (Kausambi);[f] 9 and 10, Black-and-Red megalithic pottery (Brahmagiri);[g] 11–12, Painted pottery (Rangpur[h] and Bahal[i] respectively).

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[a], [b], [c] Sankalia (3), Pls. x (b), xv and xxiii.
[d] Lal (B. B.) (2), Pl. LXXIII.
[e] Sankalia (4), Pl. xxx.
[f] Sharma (G. R.), Pl. 55.
[g] Wheeler (2), Pl. CVI.
[h] *IAR*, 1954–55, Pl. xii (b).
[i] *IAR*, 1956–57, Pl. xx. *a*.

the region of modern Bihar or eastern Uttar Pradesh, what is designated as the Northern Black Polished ware (N.B.P. ware) to which we shall return later.

Iron

Of particular significance is the fact that a number of iron objects have been discovered in association with all the phases of the Painted Grey ware ceramic in several excavated sites. The occurrence of iron at the P.G. ware levels was first reported from Alamgirpur on the river Hindon in Meerut district. At Hastinapur[a] (which probably affords the earliest evidence of the smelting as well as the use of iron) a couple of slags of iron have been found in the late levels of the Painted Grey ware horizon. Among the iron objects noticed at this place are a barbed and socketed arrow-head, a chisel and a bracelet with unconnected ends. Of the other important sites which have yielded iron objects,[b] mention may be made of Rupar (Panjab: nails, hooks, bars, spikes, knives, daggers, sickles and spearheads); Nasik (Maharashtra: leaf-shaped arrow-heads, caltrops, choppers, knife-blades, axes, drills, chisels, nails, ladles, etc.); Ujjain (Madhya Pradesh: spearheads, arrow-head, knives, crowbar types, spade, etc.); Nagda (Madhya Pradesh: knives, daggers, chisels, sickles, arrow-heads, hoes, bowls, nails, etc.); Sambhar (Rajasthan: double-edged daggers, sickles, crucibles, clasps, fish plates, braces, rings, pivots, bells, ladles, arrow-heads, spearheads, etc.); Rairh (Rajasthan: sword-blades, lances, spearheads, daggers, knives, sickles, adzes, door-fittings, etc.) and Taxila (bowl, spoons, saucepans, daggers of different types, an elephant goad, axe, adzes, chisel, tongs, anvils, nails, hoes, etc.). Further, Atranjikhera, Alamgirpur, Kausambi and Sravasti (Uttar Pradesh); Sisupalgarh and Jaugada (Orissa), Maheswar, Navdatoli and Tripuri (Madhya Pradesh); Prakash and Bahal (Maharashtra); Sonepur and Rajgir (Bihar); Bairat (Rajasthan); and Purana Quila (Delhi) are among the other sites where several iron objects have been unearthed. The date-range of most of these finds is 600–200 B.C., although the chronological pattern does not seem to be the same everywhere. It is generally believed that the iron objects discovered at Hastinapur, Atranjikhera, Alamgirpur, Kausambi and Ujjain might be earlier. A charcoal sample from an early level of Atranjikhera II gives a date of 1025 ± 110 B.C.[c] On the basis of stratigraphical evidence, it would appear that the iron objects which include small fragments and shapeless bits might have emerged on the site at Kausambi at a period earlier than that of the Painted Grey ware.[d] But it is recognized that the latter itself, with its simple painted designs, belongs to a later period at Kausambi. The foregoing illustrates how widespread was the use of iron

[a] Lal, B. B. (2), pp. 97–99.
[b] The following account is based mainly upon *Iron Age in India* by Banerji, N. R.
[c] This level has yielded a large number of iron artifacts.
[d] Sharma (G. R.), pp. 13–14.

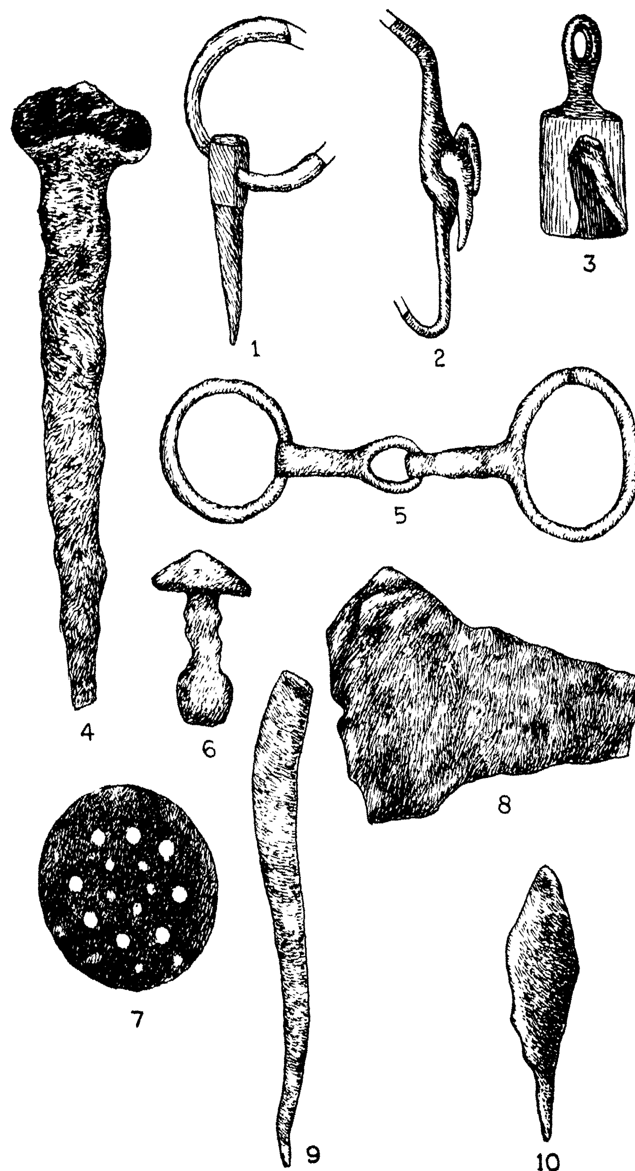


FIG. 5.5. Sketches of some ancient iron objects found at Hastinapura,[a] Taxila,[b] Sisupalgarh and Ujjain.[c] 1, door ring; 2, fragment of a chain; 3, miniature bell (Hastinapur); 4, staple from a looped head; 5, ringed chain; 6, circular piece of iron with a nail rivetted into it; 7 slightly convex iron disc with perforation; 8, lower portion of an iron axe (Taxila);[b] 9, spike of square section (Sisupalgarh);[c] and 10, spearhead (Ujjain).[d]

[a] Lal (B. B.) (2), pp. 98–100.
[b] Marshall, III, Pl. 205; Ghosh (A.), Pl. 18.
[c] *AI*, 5, p. 92.
[d] *IAR*, 1956–57, Pl. 35.

even about two thousand and five hundred years back in northern as well as central India.

In south India, a number of iron objects have been discovered in the megalithic burials, and the finds include flat axes, tanged daggers, wedge-shaped blades, spears, arrow-heads, horse-bits, sickles or bill-hooks, varieties of flanged spade, hoe and pick-axe, chisels, tripods, tridents, knives and saucer hook-lamps. The megalithic burials (which may also be called the Iron Age burials) are found distributed in most parts of peninsular India as well as in Khandesh and Nagpur. The probable date of the advent of iron in south India is supposed to be between 1050 and 950 B.C.[a] as indicated by the radiocarbon dating of the finds at Hallur in Dharwar district of Mysore State, i.e. nearly just at the same time in the north or perhaps a little earlier still, although the mode of introduction of iron into south India is yet to be established on sound evidence.[b] It is interesting to note that almost identical iron tool types have been found at various sites extending from Adichanallur in Thirunelveli district in the Madras State to Nagpur in the Maharashtra—places which are separated by a distance of almost 900 miles.

A question that naturally arises is: from where was obtained the knowledge of iron-smelting by those who brought it to India? It would appear that the production of iron from the naturally occurring ores was known in the Near East, and the earliest smelting operations of iron can be dated as far back as the second millennium B.C. and in the region of Asia Minor or the Caucasus. It has been recognized that between 1800 and 1200 B.C. the Hittitics were well known for the smelting of iron. By about 1000 B.C. there was extensive use of iron in the Near East even though iron could not replace copper and bronze which had established themselves as metals in the service of man and which quantitatively were in greater use than iron.

Presumably the Indian iron metal-workers might have become acquainted with the iron metallurgical practices of the Near East, and it might have taken some time for them to adapt those practices depending upon the availability as well as quality of the iron ore occurring in India. In course of time, however, they appear to have excelled themselves in the art of smelting and forging iron objects. It may therefore be surmized that by about 1000–800 B.C. the iron-smelting operations were in vogue in India and, in the next four to five centuries, the Indian iron and steel objects earned the admiration of the western world.

Reference has already been made to the Ṛgvedic word *ayas* which gradually began to acquire the connotation of iron.[c] The process for extracting iron, as indicated in the *Ṛgveda*, has been construed to mean by some scholars in terms of 'shining stones' (ores), medicinal plants (carbonaceous

[a] Allchin (B. and R.), pp. 227–230.
[b] Wheeler (2), p. 146.
[c] *ṚV.*, IV. 2.17; V. 30.15; V. 62.7; VI. 3.5; VI. 47.10; VI. 75.15; X. 99.8, etc.

19

material as fuel), 'fans of geese feather' (bellows).[a] It is reasonable to suppose that the small furnaces employed for the extraction of iron might have been of an open hearth type.

Among the earliest foreign accounts of the use of iron in India is the one by the Greek historian, Herodotus (fifth century B.C.), who mentions that the Indians in the Persian army used cane arrows tipped with iron.[b] Ktesias[c] speaks of two swords of Indian steel presented to him in the Persian Court. Later it has been recorded by Quintus Curtis[d] that in the gifts which Alexander the Great received from Porus of Taxila (326 B.C.) were 100 'talents' of steel. These facts illustrate beyond any doubt that by the fifth or fourth century B.C. the Indian metal-workers had attained a high degree of perfection in the techniques of producing iron and steel. Even in later times there is enough evidence to show that the Indian iron and steel had become famous, particularly in the early centuries of the Christian era. Pliny refers to swords of good quality made of Indian steel. The Romans were fascinated by the Indian steel which they imported to produce fancy cutleries and armours.[e]

Yet there is practically no recorded information of value to the understanding as well as evaluation of the metallurgical practices of India in the ancient period. Obscurity hangs over the actual methods which were adopted by the ancient ironsmiths for winning the metal from its ores. The difficulty is minimized, if not completely overcome, by the reconstruction of the remote past on the basis of some primitive methods which are adopted by tribal ironsmiths even now in certain parts of the country. There is no doubt that some of the metallic objects which have been still in existence withstanding the ravages of clime bear eloquent testimony to the ancient metallurgical practices. These will be dealt with later.

THE POST-VEDIC PERIOD AND THE CLASSICAL AGE

The post-Vedic period and later the Classical Age of India (*c.* 600 B.C.–A.D. 740) afford substantial evidence which testifies to the Indian chemical knowledge and practices of far greater import. Discernibly the chemical knowledge became refined and practices culminated in notable feats of excellence during this period. They include the production of glass and pottery, fermentation methods and dyeing techniques. Recent archaeological evidence sheds fresh light on the new achievements in glass and ceramic ware as well as metallurgical operation. There are a number of literary sources belonging to this period giving information of value on various chemical practices. Of them, particular mention may be made of the *Arthaśāstra* by Kauṭilya, the two Āyurvedic classics, the *Caraka* and the *Suśruta Saṃhitās* (original compositions may belong to the early centuries before the Christian era though the extant ones are later), and the

[a] *ṚV.*, X. 72.2; Banerjee (M. N.), pp. 432 ff.
[b] Forbes, p. 239.
[c] Warmington, pp. 257–58.
[d] Forbes, p. 239.
[e] Op. cit., pp. 239–40.

Bṛhatsaṃhitā by Varāhamihira. What follows is but a brief account, based on the archaeological and literary evidence, of some of the well-known chemical practices.

Glass

The term glass covers a wide range of substances which may differ in chemical composition and some physical properties but which possess the essential characteristics of having cooled from a state of fusion to a solid state without crystallization (under-cooling). Chemically glass is regarded as a mixture of silicates.

Though it is not clear when and where the invention of glass occurred first in the old world either in Mesopotamia or Egypt, it is now recognized that the specimens of blue glass found at Tell Asmar (in Mesopotamia) are attributable to a period *c.* 2700–2600 B.C. The cemeteries of Ur III (*c.* 2100 B.C.) and also at Assur under the Ziggurat (*c.* 1800 B.C.) in Mesopotamia have yielded glass beads. It would appear that not only glass was known in Egypt by about 2000 B.C. at the time of the XII Dynasty but even there were real glass factories there by about the fifteenth century B.C. at the time of the XVIII Dynasty in the reign of Amenhotep II (1448–1420 B.C.). Remains of a glass house and fragments of glass in several stages of manufacture have been found at the city of Tell el Amarna (1450–1400 B.C.).[a, b]

In India the Mohenjo-daro and Harappan sites have not given clues to the effect that the use of glass was known there; only glazed[c] beads of steatite or faience have been largely found. A few early objects of glass in the form of beads have been noticed at Maski, a chalcolithic site in the southern Deccan, pointing to the fact that glass was known in India at least at the beginning of the first millennium B.C.[d] But in the succeeding centuries, the glass industry steadily gained momentum and began to show signs of technical excellence which seemed to have manifested itself to a remarkable degree in the early centuries of the Christian era, as evidenced by the archaeological finds in over 30 sites. The glass objects (beads, bangles, ear-reels, eye-beads, etc.) unearthed at these sites are in various colours such as blue, green, red, white, yellow, orange and purple. In a few places some tiles and broken parts of vessels have also been found.

Of the most important sites, mention may be made here of Hastinapur, Taxila, Ujjain, Maheswar, Nasik, Bhita, Ahicchatra, Kopia, Nalanda, Nevasa, Ter, Kolhapur, Kondapur, Prakash, Brahmagiri and Arikamedu.[e]

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[a] Forbes, pp. 120 ff.

[b] Dikshit (M. G.), pp. 1–2.

[c] Glass and glaze, though produced and used differently, are similar from the chemical point of view in the sense they contain soda or some other alkali as a constituent. Glaze is applied generally to the base of some other material. Both glaze and glass are isotropic, e.g., they do not change the colour of light when tested in a polariscope.

[d] Thapar (1), pp. 107–109.

[e] For a comprehensive treatment of the subject see *History of Glass* by Dikshit, M. G., Bombay, 1969.

At Hastinapur[a] have been found beads of black and brownish colour (hardness: 5–6; sp. gr.: 2·55; probably belonging to c. 800 B.C.). They are mainly of soda-lime-silicate composition with traces of phosphates and potassium, and their colour is due to the varying amounts of iron compounds in them. At Taxila,[b] the Bhir Mound has yielded at the sixth–fourth centuries B.C. levels a number of glass beads of several shapes and colours (blue, green, red, orange, amber and black), ear-reel (dark green) with a floral design on it, 'eye-beads', glass bangles and seal. As one of the outposts of the north-western frontier of the Mauryan Empire then, Taxila was prone to receive and assimilate foreign influences in the technique of glass production. That this was so has been illustrated amply by the glass objects found later (first century B.C.–first century A.D.) at the new city of Sirkap at Taxila. The foreign glass found at this place has been recognized as lace glass, ribbed ware, swirled glass, blue and white cameo, mosaic and millefiori glass.[c] The last, it may be noted, which is known for its floral and cellular structure, was commonly produced by the Roman glass technologists, particularly those at Venice. Three glass flasks (sea- and jade-green in colour) and an upper portion of a glass bottle which have been found at Sirkap seem to be Mediterranean in origin, while the glass objects of local manufacture comprise sealings, beads of composite glass, rings, intaglios, discs, lense-like objects and large tiles. Certain specimens[d] from Taxila have been analysed chemically and, as a result, it has been noticed that the red opaque glass and strips of haematinum contain a very large percentage of lead, while the white opaque and the turquoise blue samples have significant amounts of antimony. The green-blue tiles have a high percentage of silica which confers on them the necessary hardness, and also an appreciable percentage of potash which gives them the desired durability.

Excavations at Ujjain[e] have brought to light some beads, ear-reels and bangles in stratum II (c. 500–200 B.C.), and those at Maheswar,[f] an annealed black glass seal which depicts an elephant in a lively posture (c. 400 B.C.) and ear-reels of amber colour. At Nasik[g] have been found ear-reels (c. 200 B.C.), gold-foil beads and rings. Bhita and Ahicchatra are the other places where gold-foil beads have also been found along with a number of beads of different colours. Particular mention should be made of the fact that some sites like Kaundinyapura, Ahicchatra, Ujjain, Sravasti and Sirkap have also yielded what are known as 'stratified eye-beads',[h] the technical know-how of which seems to have been borrowed from outside.

A large number of glass objects which seem to be indicative of the remains of an ancient glass factory (c. third century B.C.–third century A.D.) have been observed at Kopia[i] on the bank of the river Anoma in the Basti district of Uttar Pradesh. They are generally of soda-lime glass (sp. gr.:

[a] Lal (Dr. B. B.), pp. 13–23.
[b] Beck, pp. 24–28; Ghosh (A.), (1), pp. 41–80.
[c] Dikshit (M. G.), pp. 29–31; Marshall, pp. 688–89.
[d] Sana Ullah, p. 125.
[e] *IAR*, 1956–57, p. 27.
[f] Sankalia, Subbarao and Deo, pp. 218–20.
[g] Sankalia and Deo, pp. 96–101.
[h] Dikshit (M. G.), pp. 17–22.
[i] Dikshit (M. G.), p. 39.

2·33–2·68) with rather a high percentage of aluminium oxide (7–8 %) and some iron oxide. Blocks of glass, some of which weigh as much as 120 pounds and measure 18″×12″×9″, have also been discovered

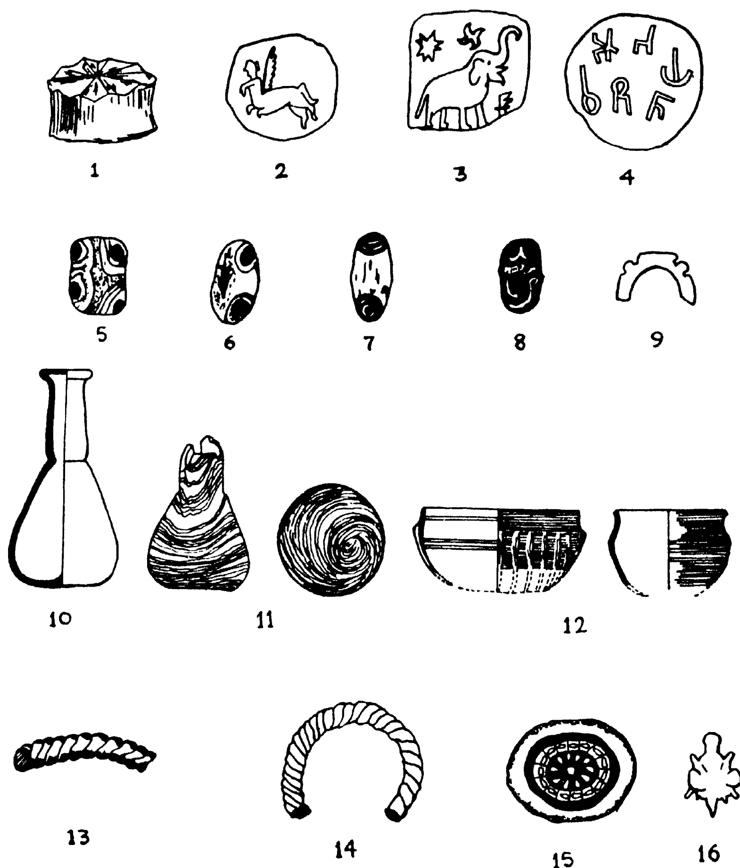


FIG. 5.6. Sketches of some ancient glass specimens.[a] 1, ear-reel from Taxila; 2–4, seals (Taxila, Maheswar and Patna respectively); 5–6, eye-beads (Bhir Mound, Taxila); 7, bead (Sirkap, Taxila); 8, bead (Ahicchatra); 9, fragment of a blue finger-ring (Ter); 10, wine flask (Taxila); 11, flask in branded agate style (Ter); 12, Roman glass bowls (Arikamedu); 13, bangle piece (Taxila); 14, spirally wound glass bangle (Nevasa); 15, millefiori glass (Arikamedu); and 16, blue glass amulet made in imitation of the *triratna* symbol (Ter).

at Kopia. Nalanda, an important seat of Buddhist learning in the ancient period, has yielded opaque, blue and green glass objects.

[a] Dikshit (M. G.), pp. 4, 11, 19, 30, 35, 42, 45, 50 and 51.

In the site at Nevasa have been observed beads of different colours including the gold-foil ones as well as small glass vessels in green and blue colours. At Ter have been found beads, finger-ring and a flask of agate-banded type which seems to be of Mediterranean origin. From the excavations at Brahmapuri on the outskirts of the city of Kolhapur have been reported a number of oblate beads of green, blue and yellow colour, and from Kondapur, beads of blue or blue-green glass with copper or cobalt as the colouring agent. The finds at Prakash include opaque as well as polychrome glass bangles and beads.[a]

Brahmagiri[b] in the southern Deccan has yielded a number of glass bangles, some of which are black while the others have yellow strips over a grey-coloured base (first–fourth centuries A.D.). At Arikamedu,[c] an early historical site on the eastern coast south of Madras, have been noticed a number of glass objects both locally produced and imported. The former comprises a number of beads in blue, green and copper-red colour. Of the latter, the noteworthy are the fragments of glass bracelets, beads (sp. gr.: 2·51–2·91; hardness: 5.7) and bowl of whitish iridescent glass and a bluish glass bowl full of bubbles and striae which indicate their Roman origin. It may be noted that there was extensive commercial contact between this region and the Roman world in the early centuries of the Christian era.

In the Sanskrit texts the term used for glass is *kāca*. Among the well-known literary works which contain references to *kāca* are *Śatapatha Brāhmaṇa*,[d] *Kauṭilīya Arthaśāstra*,[e] *Caraka Saṃhitā*,[f] *Hitopadeśa*[g] and *Bṛhatsaṃhitā*.[h] Notwithstanding the fact that both the literary works and the archaeological finds shed light on the use of glass in India over a long time, the origin of glass production in India has not been established beyond doubt. Even so there does not seem to be any doubt that the glass industry in India had made headway in the first quarters of the first millennium B.C., and that the glassmakers were skilful in controlling the temperature of fusion, moulding, annealing, blotching and gold-foiling. The different glass objects found in some 17 sites have been analysed chemically.[i] The following tables (5.1–5-4) give an insight into the chemical compositions of glass objects found at Taxila, Kopia, Nalanda and Arikamedu.

Ceramics

Mention has already been made of the Northern Black Polished ware. Bowls, dishes, lids and *handis* (carinated jars) are the general shapes of the N.B.P. ware, sometimes with decoration, which have been found in different

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[a] Dikshit (M. G.), pp. 43 ff.
[b] Wheeler (1), pp. 263–67.
[c] Wheeler, Ghosh and Krishna Deva, pp. 96 ff.
[d] *Śat. Br.*, XIII. 2.6.8.
[e] *Aś.*, **2**, 11.35, 13.41, 14.44, 14.60; **3**, 3.8; **5**, 2.23, etc.
[f] *CS. Ci.*, **17**, 125.
[g] *Hitopadeśa*, **42**, 68.
[h] *Bṛh. S.*, **42**, 8 and 10.
[i] Lal (Dr. B. B.), pp. 17–27.

TABLE 5.1

Chemical analysis of glass specimens (in percentage) from Taxila[a]

Specimen	SiO_2	Fe_2O_3	Al_2O_3	PbO	SnO_2	Sb_2O_3	MnO	Cu	CuO	Cu_2O	CaO	MgO	Na_2O	K_2O	H_2O
Red opaque glass	37·09	3·16		34·85	—	Nil	0·11	—	—	7·20	6·46	0·70	10·33	0·87	—
White opaque glass	61·32	1·70		Nil	—	5·08	0·26	—	—	Nil	9·74	1·64	20·26[b]		—
Thin drawn strips of haematinum	39·79	2·45		38·93	0·22	—	?	5·31	—	—	2·81	?	10·02	0·57	—
Green blue glass tile ..	70·57	1·60	2·46	—	—	—	0·05	—	0·55	—	4·60	2·68	14·99	2·65	—
Turquoise blue powder of decomposed glass	67·48	3·64	—	—	2·42	—	—	—	3·63	—	4·92	1·80	2·48	0·55	14·15
Fragments of a light green flask ..	68·34	1·20	1·67	—	—	—	0·34	—	—	—	8·44	1·44	17·76	0·94	0·43
Green blue glass tile ..	71·01	1·84	3·74	—	—	—	0·05	—	0·24	—	3·73	2·32	14·99	2·65	—
Amethyst glass	58·12	1·74	8·75	—	—	—	0·17	—	—	—	8·85	4·01	16·74	4·83	—
Brown glass fragments ..	53·81	8·47	1·51	—	—	—	0·08	—	—	—	6·27	4·50	23·52	2·35	—
Thin curved fragments of light blue glass	70·69	0·81	2·88	—	—	—	0·01	—	—	—	7·05	0·50	12·86	4·85	—
Blue glass bangle	68·11	2·27	2·22	—	—	—	—	—	0·44	—	4·91	3·74	19·10	—	—

[a] *AR*, 1921–22, p. 125; 1922–23, p. 158. [b] K_2O 1 per cent.

TABLE 5.2

Chemical analysis of glass specimen (in percentage) from Arikamedu[a]

Specimen	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	Na_2O	K_2O	FeO
Dull blue opaque beads ..	73·6	1·9	1·1	0·4	3·9	1·4	2·1	13·4	2·00

[a] Subrahmanian, pp. 19–20.

TABLE 5.3

Chemical analysis of glass specimens (in percentage) from Kopia[a]

Specimen	SiO_2	Sb_2O_3	PbO	Cr_2O_3	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	CuO	Na_2O	K_2O	H_2O	TiO_2
Small black perforated beads ..	62·24	—	—	—	8·46	7·20	0·02	3·13	1·55	—	16·70	—	—	0·51
Pale yellow beads	70·30	—	—	—	5·30	1·20	0·08	2·38	1·20	—	19·31	—	—	Tr.
Strips of dark blue to black glass ..	64·80	—	—	Tr.	4·90	2·95	0·06	3·71	2·10	Tr.	21·03	—	—	0·45
Green bead with black and coral red decoration	67·13	—	—	Tr.	6·70	1·50	0·03	3·03	1·60	—	19·61	—	—	0·40
Fragment of black bangle	66·13	—	—	—	7·26	0·86	0·07	2·24	1·33	Tr.	21·70	—	—	0·41
Unperforated spherical beads of clear glass	63·30	—	—	—	7·09	2·50	0·10	3·64	1·85	—	20·52	—	—	1·01
Broken pieces of pale yellow-green glass	66·60	—	—	—	6·98	1·62	0·03	2·49	Tr.	—	21·70	—	—	0·51
Deteriorated glass	60·72	—	—	—	10·80	0·20	—	8·85	1·12	—	18·30	—	—	—

[a] Roy and Varshneya, pp. 366–68, 392.

TABLE 5.4

Chemical analysis of glass specimens (in percentage) from Nalanda[a]

	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	Na_2O	K_2O	FeO	CuO	Cu_2O
1.	62·61	2·05	1·61	0·06	6·95	4·17	17·85	5·04	—	0·57	—
2.	61·21	1·81	1·60	—	8·15	3·83	18·25	4·98	—	0·75	—
3.	70·74	2·22	1·54	Tr.	2·11	0·26	15·80	4·98	—	—	—
4.	61·50	6·13	9·82	—	5·20	0·06	—	15·92	7·01	—	0·49

[a] *AR*, 1922–23, p. 158; 1930–34, p. 300.

parts of north India (hence its name)[a] and also at some places in central as well as southern India. Possibly the N.B.P. ware which, as stated already, appeared first in the region of modern Bihar and eastern Uttar Pradesh might have spread in course of time to some other parts of northern, central and southern India. In north India, they have been found in large numbers in Uttar Pradesh (Ahicchatra, Mathura, Hastinapura, Kausambi, Sarnath, Bhita, Jhusi, Masaon, Sravasti and Atranjikhera); Bihar (Patna, Rajgir, Giriak and Vaisali); Rajasthan (Bairat); Madhya Pradesh (Sanchi, Nagda, Ujjain, Eran, Maheswar and Tripuri); Bengal (Bangarh and Chandraketugarh); Orissa (Sisupalgarh); Maharashtra (Prakash, Bahal, Nasik, Nevasa, Ter and Kaundanyapur); and Andhra Pradesh (Amaravati and Chebrolu). The probable date of the N.B.P. ware spread may be about the sixth century B.C. to second century B.C.

The N.B.P. ware seems to have been made on a fast-spinning wheel, using fine clay and firing to a high temperature in kilns. It is possible, as

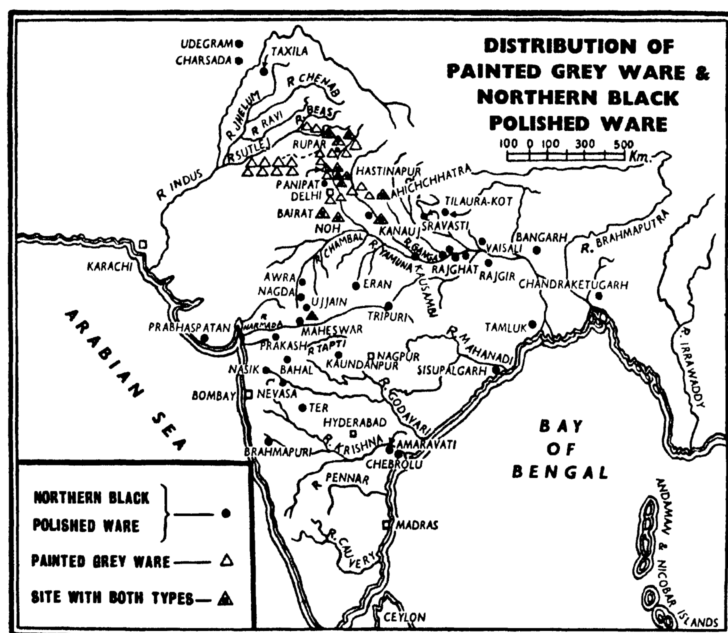


FIG. 5.7. Map showing the distribution of the Painted Grey and Northern Black Polished wares.

suggested by some archaeologists, that some of the N.B.P. wares were dressed with haematite before firing, and that the process of firing might

[a] It is indeed a misnomer to call this ware Northern Black Polished ware, although the archaeologists have been maintaining this nomenclature.

be responsible not only for the production of colour ranging from jet black to glossy-grey but also metallic sound, which are the characteristics of this ceramic. The black colour of the ware has been attributed to the presence of ferrous oxide (about 13%)[a] which would develop (by the action of reducing gases formed in the kiln) on the original highly ferruginous slip which used to be applied to the surface of the ceramic body consisting of a levigated mixture of clay and red ochre. The polishing might have been done before or after the firing. The black polished film of some samples, on chemical analysis, has been found to contain silica 46·55%, ferrous oxide 25·20%, alumina 15·53%, lime 4·74% and magnesia 3·43%. The formation of ferrous silicate may be causative of colouring the body black; and it is not unlikely that the deposition of carbon in the pores of the pottery as a result of the smoky atmosphere of the kiln also plays its role in the black coloration of the pot. There are divergent views on the chemical aspects of the N.B.P. ware. According to the analysis of the archaeological chemist in India, 'the lustre on the surface of the ware appears to be composed of some easily fusible material, possibly of organic origin, which undergoes incipient fusion at a low heat'.[b]

The chemical analysis carried out at the British Museum Laboratory shows that the unfired pots were dipped in a suspension of ferruginous inorganic material probably resembling a red earth; and that, after firing to a temperature of *c.* 800°C, the kiln was sealed so that the pots cooled in a reducing atmosphere. According to yet another analysis conducted at the Laboratory of the M.S. University of Baroda, the shining black slip might have been produced by an application of a carefully selected liquid clay, 'peptized' by the addition of an alkaline material (like *sajji-matti*, *rhe* or *khari*, which is available abundantly in the plains of the Ganga), which interacts chemically with alumina and silica of the clay. On firing, the ware is said to acquire the necessary strength as well as the glaze-like gloss on the surface.[c]

The N.B.P. ware specimens found at Taxila, probably belonging to the first or second century A.D., reveal an advanced state of workmanship and sophistication. Well-finished ware with painted lips, handles, spouts, etc., have been discovered. Decorated pottery, though rare, comprises those having painted or neatly impressed designs which include triangles, loops, festoons, common flowers, cocks or peacocks.

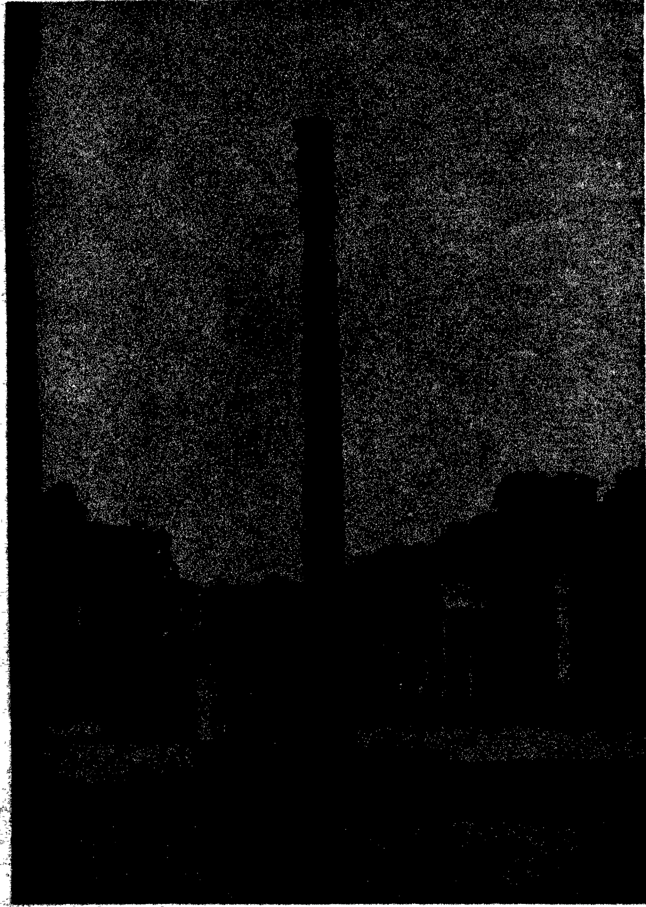
Ceramic ware with utilitarian devices continued to show signs of excellence in the Classical Age as evidenced by terracotta seals, plaques, figurines, bricks and tiles. Apart from the wheel-thrown pottery, the mould-made pots also came into use. Special types of glossy pottery too were produced using mica dust, besides those with graceful and appealing designs which included among others lotuses, certain geometrical forms, spirals and ornate pendants. At Ahicchatra have been observed

[a] *AI*, 1946, pp. 55–58.
[b] *IAR*, 1955–56, pp. 56–57.
[c] Thapar (2), pp. 73–74.



Copper Statue of Buddha, Sultanganj. (Courtesy, Archaeological Survey of India, New Delhi.) *See* p. 299

PLATE IV



The Iron Pillar at Delhi. (Courtesy, Archaeological Survey of India, New Delhi.) *See* p. 299

cylindrical pits of large dimensions which possibly were the special types of kilns for the baking of ornamental pottery and turning of tiles.

Metal-working

In the working of metals too India of this period had to its credit spectacular achievements of excellence, particularly in the Classical Age. The metal-workers skilfully worked on copper, bronze, brass and iron. The art of jewellery using precious metals and stones was in a flourishing state. A significant find connected with the jewellery craft has been reported from Ahicchatra. A solid copper bolt (24½" in length and a circumference of 14" at the centre and 12" at the ends), found in the Rampurva Asoka Pillar near Nepal border, reveals an advanced workmanship.[a]

In the Classical Age, there were centres well known for the metal industry. Vātsyāyana in his *Kāmasūtra* includes *dhātuvāda* (metal-working) in the list of 64 *kalās*. The Chinese piligrim, Hiuen Tsang, has given a description of how brass was being extensively used in India at the time of his visit, and spoken of a huge copper image of the Buddha (80 ft. in height) and a brass temple being built (height expected to reach 100 ft. or more) by Harsha.[b]

A remarkable sculpture of the Classical Age, which sheds light on the copper metal-working of the time, is the huge statue of the Buddha (7 ft. 6 in. in height and nearly a ton in weight), probably belonging to the fifth century A.D. Discovered in the ruins of a Buddhist monastery at Sultanganj (in Bihar) by an engineer of the East India Company in 1864 and now housed in the Museum and Art Gallery of Birmingham, this huge statue appears to have been cast in two layers, the outer layer by the *cire perdue* technique. The inner layer seems to have been cast in segments on a mould composed of sand, clay, charcoal and paddy husks, using iron bands for holding the segments together.[c] Some Sanskrit texts of this period, viz. *Mānasāra*, *Śilparatna* and *Viṣṇudharmottara*, give an account of the *cire perdue* process.

Another historic vestige which gives an insight into the admirably qualitative as well as quantitative workmanship of the artisans of the Classical Age is the famous Iron Pillar now located in Meharauli (Delhi) near Qutub Minar.[d] It has a height of 24 ft. 3 in. (with 1 ft. 8 in. below ground); its diameter diminishes from 16·4" below to 12·05" above. The specific gravity of the metal is over 7·5 and the pillar weighs more than six tons. Essentially made of wrought iron, its chemical composition is: iron 99·72%, carbon 0·08%, silicon 0·046%, sulphur 0·006%, phosphorus 0·114% and manganese nil. 'It is not many years since the production of such a pillar would have been an impossibility in the largest foundries of the world, and even now there are comparatively few places

[a] Neogi (2), p. 18.
[b] Majumdar (R. C.), III, p. 588.
[c] Neogi (2), pp. 20–21.
[d] Neogi (1), pp. 15–21.

where a similar mass of metal could be turned out.'[a] The probable date of this pillar is about A.D. 400, and since then it has been existing without any rust or signs of decay. The reason for this may be that a thin protective film of magnetic oxide (Fe_3O_4) might have been formed on the surface as a result of treatments given to the surface of the pillar, such as painting with a mixture of different salts, heating and quenching. It is very likely that the rather high phosphorus and the negligible sulphur or manganese content might be the factors causative of the high corrosion resistance of the pillar. In addition to this famed pillar of iron, a colossal iron pillar of bigger dimensions in two pieces and of a later date (about twelfth century A.D.) has been found at Dhar in the Malwa region as will be seen later. These examples illustrate that copper and iron metallurgical practices touched new heights during this period.

Copper Metallurgy

There has been some recent evidence which gives a glimpse of the possible techniques employed by the early metal-workers for extracting copper from its ores. Obviously the process of winning the metal from

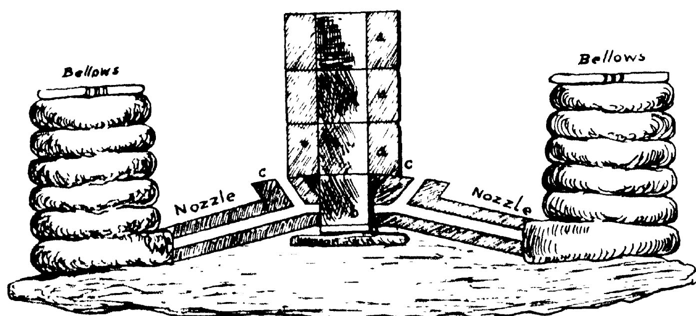


FIG. 5.8. Schematic representation of a native copper-smelting furnace at Singhara near Khetri in Rajasthan (1831).[b] (*a*) *Kothi* of three separate annular parts made of fire-clay and placed one upon the other firmly; exterior diam. of each part, 15″; height, 9″–10″; thickness, 3″; quantity of the charge: 2½ maunds (100 lb.) of the ore balls (*piṇḍi*) and 3 maunds (240 lb.) of charcoal along with some iron-bearing material to act as flux; (*b*) chamber for burning some quantity of charcoal to drive out the moisture from the newly-moulded furnace; (*c*) openings for poking the fire from time to time, being closed with moist clay after the poking operation.

the ore must have been a simple one. A process in vogue even in the last century has been described as follows.[c] The ore is crushed to a powder on an anvil of stone with a hammer. It is then mixed with cow-dung, made into

[a] Ball, III, p. 338.
[b] *Gleanings in Science*, 3, 36, 1831, pp. 380–84, Pl. xxiii.
[c] Neogi (2), pp. 63–64; Ball, pp. 239–280.

balls (*piṇḍi*) and roasted. The charge consists of roasted ore, charcoal and iron slag, the last acting as flux smelted for 9–10 hours in a blast furnace made of clay and sand. The slag is first drawn off and the smelted copper which would accumulate at the bottom of the furnace is removed the following day. The mass is again melted, refined in an open furnace using a strong blast from below, and finally cast into bars. By this method the yield of the metal is said to be 2½–7½%. It is very likely that, in ancient times also, a process not altogether different from the above was employed for the extraction of copper from its ores.

Iron Metallurgy

Recent archaeological excavations, especially at Ujjain, have given some clues to the ancient practices concerning iron metallurgy. Probably the smelting operations consisted in heating alternate layers of the ore and charcoal. There is evidence to indicate that calcium compounds were

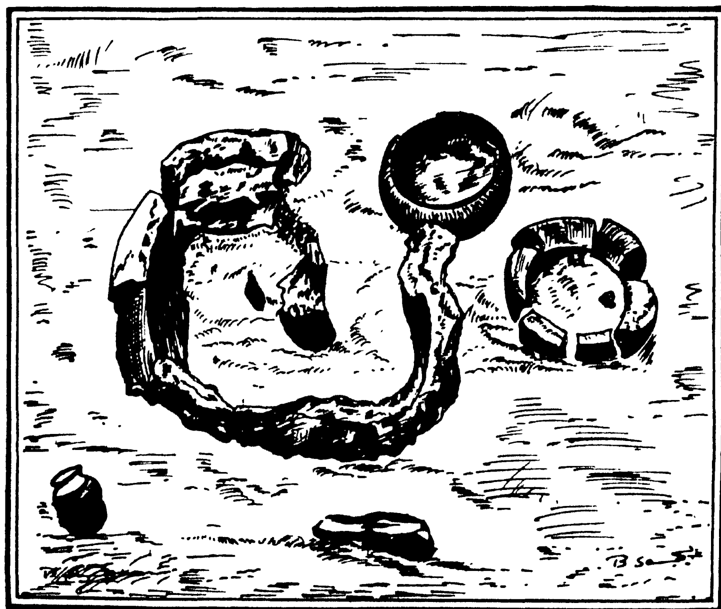


FIG. 5.9. Sketch of the remains of a furnace for forging iron objects at Ujjain (period II).[a]

also used in the metallurgical operation possibly as a flux. The charge might have been enclosed with a thick coating of clay so as to form a sort of kiln with passages for blowing in air from below, escape of gases from above and flow of molten mass from the bottom. The molten mass, after

[a] *IAR*, 1957–58, Pl. XLI B.

cooling, might have been subjected to hammering to drive in carbon and eliminate the slag. The remains of a forge, including the anvil and some iron implements, have also been found in this region.[a]

Even now in Madhya Pradesh, Bihar and Maharashtra, the primitive methods of smelting the iron ore and forging are in vogue, practised by the *Agarias* and *Khuntia Chokhs*, *Marias* and *Murias* (the tribals of Madhya Pradesh), *Birs*, *Birjhia*, *Agaria Asurs*, etc. (of Bihar), *Gonds*, *Telis* and *Mannewars* (of Maharashtra). The smelting operations are conducted generally in a vertical or slightly tilted cylindrical shaft made of clay about 3 ft. high and 3·8 ft. wide. 'The shaft tapers to the top and has three openings, a large one at the top, and two (one large and the other small) at the base. The opening at the top is for the introduction of charcoal and iron ores. Often a bamboo platform, called the *machan*, resting on poles and plastered with clay is erected on level with a top of the furnace. This platform is also provided with 3 in. dwarf walls as protective parapets and is sloped towards the opening of the furnace for sliding into it charcoal and iron ore, thus acting as an open hopper. The openings of the bottom are for maintaining the blast and for receiving the bloom and slag respectively. The aperture for receiving the bloom is significantly called the *hagan* or *loha hagora* (aperture for excretion). The wrought iron obtained by hammering the bloom is in the form of lumps or cakes. Bellows are employed for maintaining the flow of air to keep the furnance alive.' [b]

Slight variations have been noticed in different regions in the matter of using the flux and the type of furnace. While the Agarias do not use any flux, the smelters in Naziri Hills (North-West Frontier Provinces) first roast the ore and use limestone in the form of coral reefs as flux. In the Kathiawar area the furnances are rectangular in cross-section and oblong on plan.

In south India, the furnaces appeared to be circular on plan and conical in shape. Even as late as in the nineteenth century A.D.,[c] it was noticed that small furnaces made of red-potter's clay mixed with sand were being used in large numbers by the ironsmiths (in the Salem region) for the production of bar iron. The height of the conically shaped furnaces (diagrammatically shown in figure) was slightly under four feet, the diameter shaping from thirteen inches from below to seven inches at top. The charge, which consisted principally of the common magnetic iron ore and the requisite quantity of charcoal, was introduced from the top. There were two openings at the bottom; one for letting in the blast and the other for taking out the slag. Bellows of goatskin supplied the blast for heating. In about two and half hours the operation would be over yielding lumps of about 50 per cent iron. The lumps, on forging, gave the bar iron of high quality containing a considerable proportion of steel. It is on record that,

[a] *IAR*, 1957–58, p. 36.
[b] Banerjee (N. R.), pp. 182–87.
[c] *Public Cousultations* (Campbell), pp. 4160–184.

as regards their quality, the worst of them was as good as the best English iron. The price was still less than that of the market price of the cheapest English bar iron then sold in India. Indian iron was preferred by the British

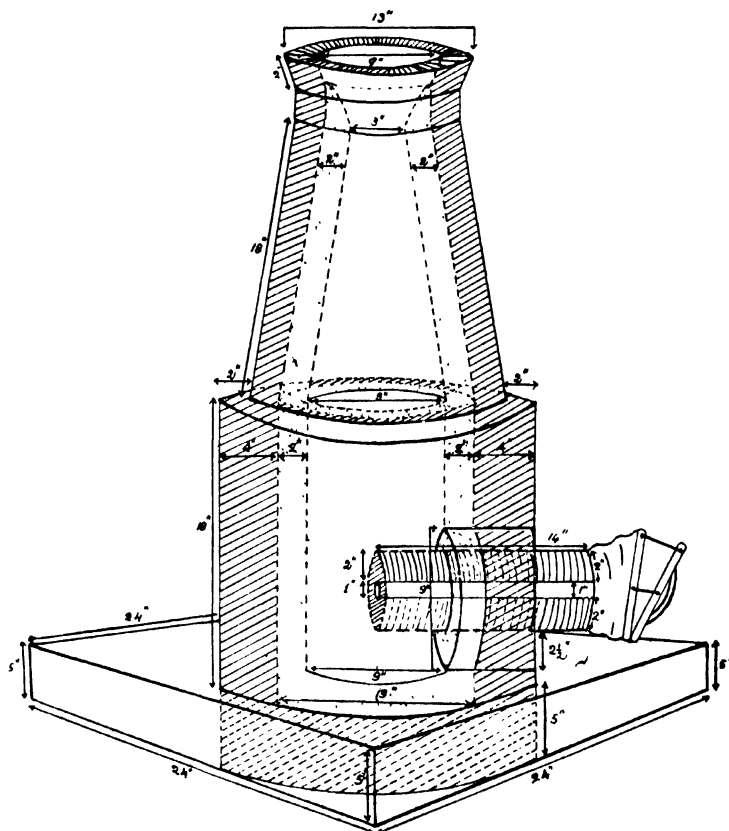


Fig. 5.10. Possible form of the furnace used by the ironsmiths of south India. (Reproduced from *IJHS*, **1**, p. 159)

for producing steel of good quality. It is very likely that the crude smelting furnances of the tribals are, probably to a great extent, the direct descendants of the ancient methods of iron manufacture in India.[a]

Literary Evidence

As stated earlier, some literary works belonging to this period throw ample light on the chemical practices which were flourishing then. Kauṭilya's *Arthaśāstra*[b] is indeed a mine of information from the point of view of the history of chemical practices in India. Even though the text does not

[a] Ball, p. 340.

[b] Kangle, pp. 111–50, 176–80.

contain accounts of analysis which would bear scrutiny from the point of view of modern chemical analysis, the observational approach and also the methods of purification, as recorded in the text, are worth noting. There is in this text a section on the examination of precious articles to be received into the treasury. Details are given of the characteristics of pearls and pearl strings, ruby, beryl and other precious substances. 'Hexagonal, square or round, of pleasant colour, having a suitable form, clear, smooth, heavy and lustrous' are the characteristics of gems while 'dull colour, with grains, with a hole in the bottom, broken, badly bored (and) covered with scratches' are their blemishes as stated in this section.

In the *Arthaśāstra*, the section on mines and factories deals elaborately with the occurrence and nature of the ores of gold, silver, copper, lead, tin and iron. It is stated that in the case of all ores, when there is increase in heaviness there is increase in metal content. 'Ore from rocks or a region of the earth, which is heavy, unctuous and soft (and which is) tawny, green, reddish or red (in colour) is copper ore.' Lead ore is 'crow-black or of the colour of the dove or yellow pigment or studded with white lines (and) smelling like raw flesh'. Iron ore is 'grey like saline earth or of the colour of a baked lump of earth'. Obviously, the physical characteristics of the ores were well known. The director of mines was expected to be an expert in the science of metallic veins, exploration of ores, metallurgy and the art of colouring gems. Among the duties of the director of mines was that he should 'establish factories for copper, lead, tin, *vaikrānta*, brass, steel, bronze, bell metal and iron, and also (establish) trade in metal ware'. Factories and commerce relating to conch-shells, diamonds, gems, pearls, corals and caustics were also contemplated.

The text also describes in detail the qualities of gold and silver. Gold which is of the colour of 'lotus filament, soft, lustrous and not producing any type of sound' is stated to be the best, the reddish yellow-coloured metal of middle quality, and the red-coloured one, of the lowest quality'. If the gold produced from the mines becomes brittle when admixed with lead, it is to be turned into leaves by heating and pounding on wooden anvils. Alternatively it could be processed by infusion with the pulp of the bulbous roots of *kadalī* (*Musa sapientum*) and *vajrā* (*Euphorbia antiquorum*). As regards silver, the text says: 'that which is white, smooth or soft is the best and the impure silver should be purified with one-fourth part of lead, and (on purification) that in which a crest has appeared at the top, which is clear, lustrous and of the colour of the curd is pure'.

The artisans of Kauṭilya's time must have been not only skilled in setting (*kṣepaṇa*), stringing (*guṇa*) and making solid or hollow articles of gold but also in the art of mixing the metals in the molten state in correct proportions. In the work of setting jewels in gold, the artisan, according to the text, should use five parts of pure gold, and two parts of gold alloyed with four parts of copper or silver. Silver with a quarter part copper, and gold with a quarter part silver were not considered to be good metals to work with. For the preparation of silver articles, solid or hollow silver

could be mixed with half the amount of gold. The *Arthaśāstra* also gives a description of different methods employed for shaping gold and silver articles. As regards minting, the text says that silver coins should be made of four parts of copper, eleven parts of silver and one part of either iron, tin or lead, while copper coins could be made of four parts of silver, eleven parts of copper and one part of iron or any other metal. Undoubtedly, these compositions must have been arrived at by the technicians after a good deal of experimentation, though the text does not contain details in this respect.

In the *Arthaśāstra* is found an account of fermented juices. 'Sugar-cane juice, jaggery, honey, treacle, the juice of *jambu* (*Eugenia jambolana*) and the juice of jackfruit infused with a decoction of *meṣaśṛṅgī* (*Gymnema sylvestra*) and long pepper, kept for one month, six months or a year and then mixed with *cidbhiṭa* (a kind of melon), *urvāruka* (*Cucumis usitatissimus*), sugar-cane stalk, mango fruit and myrobalan or unmixed (with these) constitute the group of fermented juices.' For purposes of fermentation depending upon the composition of the fermenting mixture, a ferment (*kiṇva*) was also employed. Such a ferment generally consisted of one *droṇa* of the pulp of *māṣa* beans (*Phaseolus radiatus*) raw or cooked, with one-third part of rice grains, *moraṭa* (*Alangium salvifolium*) and the like. The brewers of Kauṭilya's time seem to be well versed in the preparation of several types of intoxicating liquors such as *medaka* (prepared from rice grains), *prasanna* (flour, bark and the fruits of *kramuka*), *āsava* (wood-apple fruit, treacle and honey), *maireya* (jaggery mixed with black pepper powder and decoction of the bark of *meṣaśṛṅgī*) and *madhu* (grape juice). Yet another liquor was *mahāsurā* which was prepared from mango juice with certain essences.

The *Arthaśāstra* gives a quantitative account of the extraction of oil. 'One-sixth is the amount of oil from linseed, one-fourth from sesame' and the like. The text also has classifications such as sour fruit juices, liquids, spices, vegetables, etc., obviously based on their manifest chemical characteristics.

An important aspect that should not go unnoticed from the point of view of the Indian alchemy is that in the *Arthaśāstra*, there are descriptions of *rasapāka* and *rasaviddha*. The word *rasa* has been interpreted by some scholars as meaning mercury, and even some attempts have been made to find in these descriptions the earlier chemical practices in India based on mercury. On a deeper analysis, it becomes indeed difficult to justify the meaning of *rasa* as mercury, as probably the former means the smelted (liquid) ore.[a] The origin of alchemy in India is discussed elsewhere in this chapter.

Let us now turn our attention to the two medical classics. The *Caraka Saṃhitā*[b] gives an account of the use of several minerals, metals and metallic compounds, among which the following may be mentioned: *adrija* or

[a] Kangle, p. 121.

[b] Ray and Gupta, pp. 50 ff.

śilājatu (bitumen), *maṇḍūra* (iron rust), *añjana* (black sulphide of antimony), *suvarṇa* or *kanaka* (gold), *ayas* (iron), *kāṁsya* (bronze or bell-metal), *gandhaka* (sulphur) and *tuttha* (copper sulphate). Classifying the fermented beverages under the title of *madya varga*, Caraka describes beverages under the categories of *madirā* (distilled wine), *madya* (fermented liquor from barley, etc.), *mṛdauka* (from grape juice), *rasāsava* (from sugar-cane juice), *tuṣāmbu* (some fermented liquor from barley gruel), *mādhvīka* (fermented liquor with honey), *āsuta* (brewed mixture containing *soma* plant juice), *akṣaki* (from the chebulic myrobalan), etc. In addition are mentioned nine sources of fermented drinks: cereals, fruits, roots, wood, flowers, stems, leaves, barks and sugar; and from these as many as 84 kinds of *āsava* (wine) could be prepared according to this text.

Kāṃsya (bronze or bell-metal), *loha* (iron), *suvarṇa* (gold), *rajata* (silver), *sīsa* (lead), *tāmra* (copper), *trapu* (tin), *rajata mākṣika* (iron-silver pyrites or marcasite ore), *suvarṇa mākṣika* (iron pyrites of golden brown colour), *srotāñjana* (antimony sulphide), *śilājatu* (bitumen), *tuvari* (alum), etc., are among the metals and minerals, the properties of which are described in the *Suśruta Saṃhitā*. Of particular importance to us, are the details of processes for obtaining different types of alkalis[a] as well as their use. The term used for alkali is *kṣāra*, and *kṣāra* is among the important chemicals of Indian medicine. Alkalis are classified into three types: mild (*mṛdu*), caustic (*tīkṣṇa*) and those of average strength (*madhyama*). Generally the preparation of alkalis consists in the lixivation of the ashes of certain plants. For this purpose, some 25 plants are mentioned in the *Suśruta Saṃhitā*. The procedure described is as follows: Select pieces (wood, leaves, roots and fruits) of the plants are piled up, a few pieces of limestone kept on them and the whole thing then burnt to ashes. Thirty-two measures of this ash are stirred with six measures of water, and strained through cloth, and the process is repeated 21 times. The extract thus obtained is concentrated by boiling it in a large iron pan. During boiling, it is constantly stirred by means of a ladle till the liquid becomes clear, pungent and soapy to the touch. At this stage the desired quantities (eight measures) each of burnt limestone and conch-shells are heated strongly in an iron pan. The mass is then mixed with three quarters measure of the above-mentioned liquid and evaporated to obtain a solid residue which is then mixed with 64 measures of water and thoroughly boiled, with constant agitation by means of a ladle till a concentrate of the required consistency results. The concentrated solution is now decanted and preserved in closed jars. This is *madhyama kṣāra*.

If the alkaline extract is boiled to a proper consistency without the addition of the burnt shells, an alkali of mild strength (*mṛdu kṣāra*) is said to result. On the other hand, if the alkaline extract is repeatedly boiled with the ashes of some more plants, the product is stated to be a caustic or strong alkali (*tīkṣṇa kṣāra*). The foregoing descriptions amply illustrate

[a] *SS. Sū.*, 11.

the experimental technique employed and also the nature of quantitative considerations of which the experimentalists were well aware. The method of preparation of *kṣāra* was considered to be an art (*kalā*) and, in fact, it was recognized as one of the 10 important arts of the Āyurveda.

Apart from the triple distinctions made of alkalis with reference to their strength, three other types of alkaline substances have also been mentioned. They are the carbonate of potash (*yavakṣāra*), trona or natron (*sarjikakṣāra*) and borax (*ṭaṅkaṇa*). Hot alkaline solutions were generally used for treating thin sheets of metals like iron, gold or silver before their incorporation into drug compositions. Caustic alkalis also found use for treating surgical instruments which were used for incisions, punctures and scarifications of the diseased parts of the human body. The word *kṣāra* significantly connotes the removal of the unhealthy portions of the body, be it of the skin or flesh.

Ancient Indians, in particular the physicians, knew a number of salts. The *Suśruta Saṃhitā* mentions the following six types of salts:[a] (1) nitre (*sauvarcala*, i.e. potassium nitrate); (2) rock salt (*saindhava*, i.e. sodium chloride with potassium chloride); (3) a reddish brown granular salt (*viḍa*), probably consisting of a large part of sodium chloride with traces of sodium sulphate, alumina, magnesia and iron compounds; (4) fossil salt (*audbhida*), probably a saline deposit consisting chiefly of sodium carbonate and magnesium sulphate; (5) sea salt (*sāmudra*, sodium chloride with traces of magnesium salts); and (6) a kind of saline earth (*romaka*).

A number of acids were also known. The organic acids of citrons, tamarind, pomegranate and of a few other plant products were in use. The earlier texts on medicine do not speak of any mineral acid. In this connection it may be noted that some of the compositions including nitre and alum used by the Indian alchemists for the purification of metals might have constituted the ingredients necessary to give rise to mineral acids in the process, although there is no explicit reference to the mineral acids. The Indian experimentalists did not seem to have any knowledge of the mineral acids in contradistinction to the acids of plant products of which they were quite aware. It may be mentioned that the *Rasa Pradīpa*, an iatro-chemical text probably belonging to the sixteenth century A.D., gives a detailed process for the preparation of a mineral acid called *śaṅkhadrāvaka* (i.e. one which dissolves conch-shells); the *Suvarṇatantra*, an alchemical text possibly of a later date, speaks of *śaṅkhadrāvaka* as a universal solvent, and also refers to its property of dissolving metals. From this it seems that the Indians did not possess the knowledge of the use of mineral acids for dissolving metals before the sixteenth century A.D., though some of the processes employed were in the nature of obtaining solvents of the type of mineral acids.

The *Bṛhatsaṃhitā* by Varāhamihira is another important literary source which gives detailed information on the preparation and use of fine chemicals like perfumes, scented hair-oils, etc.[b] Evidently, the chemical

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[a] *SS. Sū.*, 46, 111.

[b] *Bṛh.S.*, 77, 1-17.

techniques relating to them had reached an advanced stage during the time of Varāhamihira. Some of the preparations are worthy of mention. In the chapter on *gandhayukti* (preparation of perfumes) several recipes are given of compounded or delicately blended perfumes. It has been stated that *gandhārṇava* (ocean of perfumes) can be prepared from 16 substances, if every four of them are permuted variously as desired, and in proportions of one, two, three or four parts respectively. *Vālaka, spṛkka, aguru, madanaka, dhānya, karpūra, cola, ghana, śaileya, nāgapuṣpa, vyāghranakha, nakha, tagara, karcūra, malaya* and *uśīra* are the 16 substances mentioned. Not all these substances have been identified from the modern scientific point of view. Perhaps *vālaka* may be a kind of *andropogan* and *aguru*, a fragrant aloe wood. What is worthy of note is the quantitative approach to blending the perfumes of desired quality. Varāhamihira, in a tabular form, describes how a number of perfumes of high quality can be prepared and says that the number of perfumes resulting from the 16 ingredients mixed in all possible combinations is 174,720.

The *Bṛhatsaṃhitā* gives an account of some adamantine compositions like *vajra-lepa* and *vajra-saṃghāta.*[a] *Vajra-lepa* consists of extracts of certain types of plants, fruits, seeds, barks, etc. (like unripe ebony fruit, wood-apple), blossoms of silk cotton and *guggulu* (a fragrant gum; exudation of *Amuris agallochum*). The process described is as follows: 'Boil them in a *droṇa* of water and reduce it to an eighth of its original volume. Mix the residue with *srīvāśaka* (probably the resin of *Pinus longifolia*), *kundurūka* (exudation of *deodar*), *guggulu*, linseed, resin of *bilva* fruit, etc., and make it into a paste.' This glutinous material could be applied on to the roofs and walls of temples and mansions. Its life has been stated to be ten million years. *Vajra-saṃghāta* is a metal-cement consisting of eight parts of lead, two of bell-metal and one of iron rust or brass. It is melted and poured hot as desired.

PIGMENTS

The remains of ancient paintings at Ajanta (second century B.C. to sixth century A.D.), Bagh (third to fifth centuries A.D.), Badami (sixth century A.D.) and Sittannavasal (seventh to eighth centuries A.D.) give an insight into the use of colours as well as the technique of painting adopted during this period. The principal colours used are *dhāturāga* (red ochre), *haritāla* (yellow ochre: arsenic sulphide), indigo blue, *lapis lazuli* blue, *kajjala* (lamp black; carbon), *khaḍi-māṭi* (chalk white), *geru-māṭi* (*terra verde*) and *jangāl* (green-coloured verdigris). The technique consisted of (i) preparation of the ground in the form of a rough plaster and upon it a fine plaster, and (ii) application of the desired colours on the ground. The rough plaster was generally a ferruginous earth consisting of iron oxide, powdered rock, clay, vegetable, fibres and

[a] *Bṛh.S.*, 57, 1-8.

paddy husk. The plaster was levelled and polished with a trowel or a polishing stone. The fine plaster was one of white lime wash (to a thickness of about 0·1 mm.) applied to the rough plaster when the latter was still wet. The ground was allowed to dry. Animal glue was used so as to serve as the binding medium for the pigments used. The *Viṣṇudharmottara Purāṇa* describes the preparation of the ground for painting in a methodical way.

To sum up, the main features of the chemical knowledge and practices in India during the post-Vedic as well as the Classical Age seem to bespeak a concerted and methodical approach. Needless to add that they attracted the attention of the contemporary world. Nevertheless, we are in aridity regarding the theories concerning these practices. And techniques of excellence went ahead of theorizing tendencies. But towards the close of the period under reference, a new way of understanding certain chemical substances and an equally new way of processing them for a purpose that was at once sublime and mystical came on the scene. An esoteric theoretical approach supported by an experimental technique of an entirely different character attracted the attention of a particular section of people who had faith in the ideals and practices of what is known as Tantrism. These constituted the base for alchemy and iatro-chemistry in India.

ALCHEMY

Alchemy is the forerunner of modern chemistry. The latter, about two hundred years old, has developed as a result of experimentation, observation and inference. The former, on the other hand, for over two thousand years revolved round only two objectives, viz. (i) the transmutation process for converting base metals (like lead, tin, mercury or copper) into the noble metals (gold or silver); and (ii) preparation of the Elixir of Life for attaining immortality. The objectives were in fact two sides of the same coin. For, they were concerned with the problem of change. In one case it was a change from the inferior metal to the superior one; in the other, it was a change from the despised old age to the exhilarating youthful state. To achieve these objectives the alchemists developed complicated processes and secret practices, whose number was legion, involving metals, minerals and herbs. The alchemists, too, had their laboratories in which they ceaselessly endeavoured to prepare gold artificially and to evolve the Elixir of Life. But, more often than naught, their endeavours appeared to be not only mysterious but even superstitious. In addition, mystical methods, astrology and allegory influenced not inconsiderably the alchemical ideas and practices.

A brief historical account of alchemy is desirable to understand the origin of alchemy in India in a perspective.[a, b, c] The word 'alchemy' is Arabic (*al-chemy*). It seems to have been derived from the Egyptian *khem-it*

[a] Holmyard, pp. 17 ff. [b] Read, pp. 12 ff. [c] Taylor, pp. 40–55.

(the black) or the Greek word *chyma* (black molten metal). Probably the art of transmutation of base metals into gold was flourishing in Egypt (the country of the black soil) when the Arabs came to know of it. In Greece, alchemy was a favourite practice among metal workers. The Arabians are said to have added the article *al-* to *chyme* or *chaemea*.

The origin of alchemy is indeed obscure. However, in different periods of history, alchemical thought and practices were extremely popular in China, Egypt, Greece, India, Arabia and Western Europe. There is a reasonable view held by some scholars that China might have been the original home of alchemy. Chinese alchemy seems to be very ancient, probably belonging to the early centuries before the Christian era, though Wei-Po-Yang, the well-known Chinese alchemist, produced the first alchemical treatise only in the second century A.D. The Chinese had reverence for cinnabar (mercuric sulphide) which occurs naturally in China. They considered it as the energetic essence and bestower of long life. The two components of cinnabar—mercury and sulphur—were supposed to be the *yin* (female) and *yang* (male) principles respectively.[a] This concept was in perfect accord with the Chinese religio-philosophic system known as Taoism,[b] which not only enunciated its own *yin* and *yang* principles to interpret nature and man but was also concerned with material life and immortality. It is possible that Chinese alchemical practice might have found its roots in these ideas, with cinnabar as the prime substance. For centuries the alchemists of China indulged in strange practices for obtaining the 'medicine' or a 'pill of immortality' as well as converting mercury or base metals into gold. It is not unlikely that the cinnabar-centred Chinese alchemical thought might have influenced similar ideas in other countries which in turn appear to have modified the main alchemical theme to suit their own religio-philosophical speculations.

The history of alchemy tells us that this ancient practice was not all fiction and mystery. For example, in Alexandria in Egypt, as alchemy grew, it tried to acquire a rational basis. By about the fifth century B.C., the Greek thinkers had developed a theory of four elements: *earth*, *fire*, *water* and *air*, and the four primary qualities: hot, cold, dry and moist. Aristotle (384–322 B.C.) conceived of these elements and their qualities as emphasizing the unity of matter amidst all the changes.

The 'primary matter' as he called it could undergo transformation into different substances depending upon the primary qualities affecting it. Thus, for example, the primary matter, a potential one, would become *earth* with the pair of primary qualities, cold and dry; *water* with cold and wet; *fire* with hot and dryness; and *air* with hot and wetness. In any case this theory appeared to explain satisfactorily the problem of change.[c]

The alchemists of the Hellenistic culture of Alexandria in Egypt were quick to realize the importance of this theory; for this theory held out the possibility of transmuting base metals into gold or silver by changing

[a] Mason, pp. 55–57. [b] Needham, II, pp. 33 ff. [c] Taton, I, pp. 231–32.

their qualities. A change in qualities meant the emergence of a new metal and this perhaps represented the transmutation process. Of the qualities, *colour* was the most perceptible one, and the attempt was to bring about a change in colour of a metal like copper or tin, to that of gold or silver. The concept of change received support also from astrological beliefs. It was

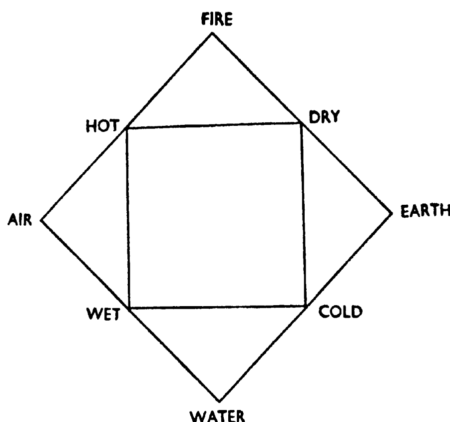


FIG. 5.11. The four 'elements' of the Greek thinker, Empedocles.

thought that a base metal could be converted into a noble metal under proper astrological influences. The then known metals were also associated with the sun, moon and the planets. If the Greek theory of matter was one, the astrological belief was another which shaped the later alchemical thought in Egypt. Pseudo-Democritos (Bolos) probably belonging to the second century B.C. and Zosimos who lived in the fourth century A.D. were the noted exponents of alchemy in Egypt.

Alchemical practice in Egypt came under yet another influence. The skilled metal workers and other artisans attached to the temples knew the 'dyeing' of metal, stone and fabrics. They were also adepts in the art of producing cheaper substitutes for gold or silver. To them, then, alchemy meant an occult gift enabling them to transform the inferior metals to the noble metals too. Only they thought that the inferior metal should be 'killed', obtained in a native state and then processed suitably to transmute them into either silver or gold.

In the Middle Ages alchemy was dominant in the Arabian countries. The Arabic alchemy, which appears to have drawn its ideas from the alchemy of Alexandria as well as that of China, specially emphasized what has come to be familiarly known as the sulphur-mercury theory. All substances, in particular metals, were regarded to have been formed by the interaction of the two principles, *Sulphur* and *Mercury*. Sulphur represented an abstract

principle composed of hot and dry, while mercury represented cold and moist. In essence, sulphur (the Sophic-sulphur as it was called to distinguish it from ordinary sulphur) meant the property of combustibility and stood for the element *fire*. Sophic-mercury meant the fusibility of metals and stood for the element *water*.

The alchemical sulphur-mercury theory developed also on mystical lines. The mystic sect, called the 'Brethren of Purity', was the chief exponent of Islamic alchemy. The conception upheld by the Brethren of Purity was that macrocosm was recapitulated in microcosm, the man. They thought of even the natural substances like metals and minerals in terms of 'bodies' and 'spirits' corresponding to the human body and soul.

Most of the Arabic alchemical works have been attributed to one by name Geber or Jābir ibn Hayyān (about eighth century A.D.) who classified substances into *spirits*, *metals* and *bodies*. He also emphasized the operational qualities such as fusion, combustion, evaporation, pulverization and malleability. Geber himself was a great experimentalist in a number of medicinal preparations as well as an alchemist.

It would appear that the Islamic alchemy gradually found its way into western Europe by about the twelfth century A.D. The Arabic texts on alchemy were translated into Latin. Mystical representations and symbolism of alchemy found new and faithful followers. Of great interest was the spectacular emergence of a number of esoteric symbols including those of the masculine and feminine, the active and the passive. The synthesis of Sophic-sulphur and Sophic-mercury, the two principles of union, was considered to be the 'Philosopher's Stone', the perfect and potent transmuting agent. This is a concept of the later European alchemy. In line with the Philosphcr's Stone was the life-prolonging agent which would transmute man from a state of ageing to one of long life, and went under the enchanting name, Elixir of Life. The Philosopher's Stone as well as the allied Elixir of Life were the goal sublime of alchemists, ever in sight and never reached.

The imagery of Sophic-sulphur and Sophic-mercury went further and even included 'Philosophical water', also called 'menstruum', associated with the Philosopher's Stone.[a] In later alchemical writings, these enigmatic and mystical ideas found different expressions which are too numerous to be recounted here. A characteristic of them was the form of a union of masculine-feminine principles and a conjoining liquid called menstruum which was supposed to serve as a medium for the union. The menstruum was symbolically represented in the form of a dragon or serpent which was, in fact, an important alchemical imagery bound with religious and mythological conceptions. Religion, mythology, number-superstition and symbolism exerted profound influence on the European alchemy too.

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[a] Read, p. 9.

Indian Alchemy and its Characteristics

In India, the alchemical ideas grew also around a male-female symbolism; and the symbolism was naturally cast in an indigenous imagery. In a mythologically erotic background mercury is conceived as the male principle (symbolically as the seminal essence of Śiva) and sulphur as the female principle (symbolically as the menstrual flux of his consort or of the celestial nymphs). In its twin aspects, viz. efforts to transmute base metals into gold and the pursuit of the Elixir of Life, alchemy does not seem to have made its appearance in India before the fifth or sixth century A.D. But in the next seven or eight centuries, the Indian alchemy had considerable following. This was the period of what is known as tantrism which admitted into its fold all, irrespective of caste, sex and creed.[a] The Indian tantrism which is a peculiar complex of thought and practice represents a human urge not only to attain material prosperity and immortality but also to unite with the divine by adopting diverse practices.[b] Alchemy was adopted possibly as part of the mystic practice by certain sections of the tantriks in India.

The Sanskrit equivalent in general of the term alchemy is *rasavidyā* and that of the alchemist, *rasavādin*. The word *rasa* as used in the alchemical literature means mercury. It should be emphasized that mercury is central to the whole Indian alchemical thought and held in veneration because of its presumed mythical origin (the creative energy of Śiva, one of the Indian Divine Trinity). As a result, mercury itself stands out as divine in the alchemical practices, preparations and processes. Mercurial preparations are supposed to give long life, youthful vigour, high mental powers and even the rare faculty of moving invisibly in space (*khecara-gamana*). Significantly mercury is also referred to as *pārada* which literally means that it enables human beings to 'cross the ocean of life'.

There does not appear to be any theoretical basis for the alchemical thought in India, as the theory of four elements which, as stated before, supported the western alchemy in the early centuries of the Christian era. Searching in vain for such a sustaining theoretical content, one is struck, instead, by certain characteristics of the Indian alchemical literature such as the praise of mercury in the introductory portions, explanations of the origin of lead, sulphur, mica and a few other substances also in a mythical way, the eight *mahārasas*, the eight *uparasas*, the eight *dhātus* or metallic substances and also precious stones, elaborate processes for purifying alchemical substances, use of herbs and symbolical forms (*paribhāṣā*). Above all, the well-known texts themselves are unfolded in the form of a dialogue between the male God and *Śakti* (his feminine energetic part). Some of these texts even speak of the eight *siddhis* in the same way as the tantrik texts. The eight *siddhis* (*aṇimādi aṣṭasiddhis*) relate to powers of assuming minute dimension (*aṇimā*), huge dimension (*mahimā*), lightness (*laghimā*), heaviness (*garimā*), obtaining everything (*prāpti*), possessing objects of

[a] Avalon, pp. xxix ff.

pleasure (*prākāmya*), attaining supremacy (*īśitvā*) and subduing or bewitching (*vaśitvā*).[a]

The foregoing characteristics and the fact that there are in these texts passages which speak of initiation and ritual practices, similar to those found in the tantrik texts, unmistakably point out that these alchemical ideas could not have but flourished in India at a time when tantrism was a dominant practice.

Literature on Alchemy in India

The literature on Indian alchemy is notably voluminous. But it is not of a varied type, because generally the texts have more or less the same form and tone. Also the presentation of the tantrik elements is nearly the same in these texts. Nevertheless, the alchemical texts are not usually recognized as part of the tantrik literature.[b] They come under the category of the *rasaśāstra*, signifying a systematic treatment of the new knowledge and practice relating to the use of mercurial compounds and a host of other substances as medicines. In fact, the *rasaśāstra* texts are, by and large, the iatro-chemical texts.

The dates of most of these texts are generally uncertain, but they belong possibly to a period between the ninth and the eighteenth centuries A.D., the period between the tenth and the fourteenth centuries being perhaps the most flourishing one. The following are among the important *rasaśāstra* texts in Sanskrit: *Rasahṛdaya* by Govinda Bhāgavat, *Rasaratnākara* by Siddha Nāgārjuna, *Rasārṇava* (author unknown), *Rasendracūḍāmaṇi* by Somadeva, *Rasaratnasamuccaya* by Vāgbhaṭa, *Rasaprakāśasudhākara* by Yaśodhara, *Rasaratnākara* by Nityanātha Siddha, *Rasarājalakṣmī* by Rameśvara Bhaṭṭa, *Rasendracintāmaṇi* by Rāmcandra Guha, *Rasasāra* by Govindācārya, *Rasakaumudī* by Jñāna Candra, *Rasabheṣajakalpa* by Sūryapaṇḍita, *Rasasaṅketakalikā* by Cāmuṇḍa (Cūḍa), *Lohapaddhati* by Sureśvara, *Kaṅkāligrantha* by Narasiṃha Śotri, *Rasamuktāvali* by Devanātha, *Rasapaddhati* by Bindu Paṇḍita, *Rasāmṛta* by Rāmeśvara, *Rasanakṣatramālikā* by Mathanasiṃha, *Rasendrasārasaṃgraha* by Gopal Kṛṣṇa Kavirāja, *Pāradayoga Śāstram* of Śivarāma Yogin, *Rasaratnamālā* of Narasiṃha Kavirāja, *Rasamaṅgala* of Gahanānda Muni and *Rasarājaśaṅkara* of Rāma Kṛṣṇa. In addition, there are a few works whose authorship or dates have not been established yet beyond doubt. Among them may be mentioned *Kailāsa Kārakam*, *Gandhaka Kalpa*, *Pārada Kalpa*, *Dhātumāraṇa*, *Dhāturatnamālā*, *Dhātuśuddhi Prakaraṇa*, *Jāraṇamāraṇādi*, *Tāmrabhasmavidhi*, *Yantroddhāra*, *Rasadruti Prakaraṇa*, *Rasavaiśeṣikam*, *Rasagrantha*, *Rasanighaṇṭu* and *Rasarañjana*.

Studies concerning the *rasaśāstra* texts made so far indicate that most of the important texts have come to light and those which are to be studied still contain material of alchemical value perhaps not sub-

[a] Bhattacarya, II, p. lxxx.

[b] Bhattacarya, II, p. xxi.

stantially different from what has been known. Nevertheless, there are a few admittedly tantrik texts which deal with alchemical ideas as part of their psycho-experimental-symbolic treatment of the tantrik goals and related practices. Among them mention may be made of *Mātṛkābhedatantram*[a] and *Rasārṇavakalpa* of the *Rudrayāmala*[b] in Sanskrit. Besides there are a number of texts in a few languages other than Sanskrit, like Tamil, Telugu, Kannada, Malayalam, Bengali, Marathi, Oriya and Gujarati. Particular mention should be made of the Tamil texts. There appear to be about two hundred works in Tamil on the Siddha system of medicine having alchemical ideas and of them special importance attaches to the *Amudakalaijñānam, Muppu, Muppuvaippu, Muppucuṇṇam, Carakku, Guruseynir, Paccaiveṭṭu-sūtram* and *Pannīr-kāṇḍam* by Agastya; *Kaḍaikāṇḍam, Vālalai-sūtram* and *Naḍukāṇḍam* by Konganavar; *Karumāna-sūtram, Cuṇṇakāṇḍam, Pañcamītram, Vāda-sūtram, Sendūra-sūtram, Gurunūl, Karumāna-sūtram* and *Vakāra Kalaṅgu* by Ramadevar; *Karpam* and *Vālai-sūtram* by Bogar; *Karagappa, Pūrva Muppu-sūtram* and *Dravakam* by Nandīśvar; *Vādakāvyam* by Karuvurar; *Muppu-sūtram* by Romarṣi; *Karpavidhi* and *Sūtram* by Kailāsa Muni; *Vākyam* by Macca Muni; *Sūtram* by Suryanandar; and *Jñānam* by Satya Muni. So far these texts have remained practically unstudied and a comparison between the Sanskrit and the Tamil sources would be possible only when the latter are studied in detail with reference to their alchemical ideas.

Early Ideas on Rejuvenation

At this stage, it is desirable to understand the difference between the alchemical concepts of attaining perpetual youth as well as immortality, and the ancient ideas on rejuvenation. The former are in the main concerned with the use of certain compositions in an esoteric way, faith and symbolism playing a dominant role in such uses. The latter, on the other hand, are in the nature of well thought-out therapeutic procedures which are not governed by esoteric considerations, but by their physiological effects.

In ancient times, the Indians had developed not only exhilarating elixirs but also compositions for rejuvenation. But they had no alchemical undertone. In the *Ṛgveda* are found references to *somarasa*, the juice extracted from the *Soma* plant (*Sarcostema viminalis* ?). *Somarasa*, an exhilarating elixir, was regarded even as a drink of the immortal gods. There are nearly a hundred and twenty hymns of the *Soma* in the *Ṛgveda*. A close examination of these hymns, however, reveals that the *Soma* juice is extolled as a divine drink which gives vigour, wealth and happiness. Nevertheless, it should be noted that this intoxicating drink used to be taken along with milk, clarified butter or barley only by the priests and the privileged during the performance of sacrifice (*yajña*).

The Āyurvedic classics, the *Suśruta* and *Caraka Saṃhitās*, have given due importance to the compositions used for increasing virility and longevity.

[a] Subbarayappa and Roy, pp. 42–49. [b] Roy (M.) (2), pp. 137–42.

The practitioners of Āyurveda were as much concerned with the cure of the bodily diseases as with the maintenance of youthful form and vitality of the body as it aged. Increased powers of mind, a total immunity possibly against all diseases, good fortune and charming personality were also their goal. The medical treatment known as *vājikaraṇa*, for increasing the strength and virile power, forms a part of the *cikitsā* as explained in the *Caraka* and the *Suśruta Saṃhitās*. For this purpose, a number of compositions are mentioned and these, however, do not make even a reference to mercury. The *Suśruta* mentions the *rasāyanas*[a] (elixirs and rejuvenators) capable of making a human body possess an almost life-long youth and extraordinary mental faculties. It also speaks of compositions (e.g. *śatapāka vacāghṛta*) which could make one live for five hundred years. In the preparation of these *rasāyanas*, it may be noted, metals are not used. Essentially the *rasāyanas* are herbal although sometimes gold is used along with other substances of vegetable origin.

Soma as an elixir finds a place also in the *Suśruta Saṃhitā*. The *Soma* elixir is supposed to enable one to live for ten thousand years with a youthful body and all the enjoyments associated with it. It is claimed that he who consumes this elixir becomes superhuman, and that his muscular energy will not be inferior to the combined powers of a thousand wild elephants. He can move about in space freely and majestically with resplendant personality. Nevertheless the *Soma* elixir could be taken only by the select section of the population.[b]

The other Āyurvedic classic, the *Caraka Saṃhitā*, in its sections on *vājikaraṇa* and *rasāyana* which form part of the *cikitsāsthāna*, describes certain processes and recipes for giving unrivalled strength to the body and a longevity of even a thousand years. A number of other vitalizers of vegetable origin are also mentioned. A reference, however, is made to the use of metals like iron, gold and silver as components of certain elixirs. Again, as in the *Suśruta*, the emphasis in the *Caraka Saṃhitā* is still on herbal preparations. One could live as long as ten thousand years without any ailment by drinking extracts of some of them. Like the *Suśruta*, the *Caraka* also enjoins that the rejuvenation and virilification are meant only for the privileged castes.[c]

Possible Origin of Indian Alchemy

But to live long in perpetual youth and to experience that which is divine in this very life have a strong appeal to every human being. These human inclinations incessantly try to surpass the privileged attitudes and rigid caste structures, and go out in search of systems of thought and practice conducive to their realization. In India, the tantras offered such a system of thought and practice in an ingenious manner. The tantrik *siddhi* was thought of in different forms such as *janmaja* (due to birth), *oṣadhija*

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[a] *SS. Ci.*, **26**, **30**. [b] *SS. Ci.*, **29**, 8. [c] *CS. Ci.*, **4**, 38.

(due to some medical elixirs), *mantraja* (due to magic syllables), *tapoja* (due to penance) and *samādhija* (due to meditation).[a] The tantriks endeavoured to attain the *siddhis* by several paths, one of them being the use of certain compositions containing compounds of mercury, sulphur, mica and several other metallic substances. To achieve the highest in this life itself the tantras advocated preservative medicaments to the body in esoteric ways. In this respect, mercury as well as mercurial preparations, sulphur and mica assumed great importance and so became intertwined with the tantrik male-female symbolism and ritual practices.

Now what may be the origin of the mercury-based alchemy in India? It would appear that the Indian tantrism during its diversified growth had absorbed some Chinese elements also.[b] The orthodox tantrik texts, like the *Yāmala*, speak of Mahācīna as a place to be visited for attaining *mahāsiddhi*. There is also a view that the Buddhist alchemist, Nāgārjuna, went to Mahācīna under the name of Vaśiṣṭha for this purpose. Nīla Sarasvatī, a tantrik goddess, is stated to be Chinese in origin while another tantrik goddess, *Tārā*, is believed to have emanated from the country of Bhoṭa (now comprising Tibet).

As indicated before, the alchemical literature in Sanskrit is presented as a dialogue between Śiva and Pārvatī in their different forms, of which perhaps the most significant are the forms of Bhairava and Bhairavī. Śiva is also worshipped in a form known as *liṅga*. Of significant interest in this respect is the fact that in Tamil, *liṅgam* means cinnabar (mercuric sulphide) also, and that cinnabar forms one of the constituents of a composition (*aṣṭabandha*) used during the installation of divine idols. Tradition has it that cinnabar is the source of divine energy and possesses the creative principle.

In its fully developed form, the mercury-based alchemy in India relates to the male-female symbolism (Śiva and Pārvatī), the Bhairava form of Śiva as the creative emblem, and its association with cinnabar. As stated already, the Chinese alchemy centred round cinnabar, the compound of *yang* and *yin*. Though Chinese alchemy is old (*c.* third century B.C.), Taoism and Chinese alchemy were flourishing in China during the Tang period. Historically the cultural intercourse between India and China was notable between the third and the seventh centuries A.D.[c] It is reasonable to presume that the alchemy based on cinnabar and its male-female symbolism might have attracted the attention of the Indian tantriks during the same period. But in its growth in India, this alchemy had to adapt itself to the corresponding Indian elements, including the mythico-religious practices. The followers of the tantras might have modified it with their own originality. The most remarkable fact is that, in a century or two, the alchemical knowledge became formalized in a way characteristically Indian. Perhaps because of this, even the male-female symbolism found

[a] *Y.Sū.*, 50.

[b] Chakravarti (C.), p. 46; chs. 6–8; Bagchi, pp. 2 ff.

[c] Needham, I, pp. 206–14.

a different expression. In the Chinese alchemy, mercury is the female principle and sulphur the male principle, while opposite is the case with the Indian alchemy.

Nevertheless, it must be emphasized that the possibility of interaction between the Islamic alchemy and the Indian alchemy at some stage cannot be ruled out, even though evidence to this effect is scanty at present. One of the Siddhars of Tamilnadu, Ramadevar, says in his work on alchemy[a] that he went to Mecca, assumed the name of Yakub and taught the Arabians the alchemical art. It is significant that some of the purification processes and substances of alchemical significance are common to both the Islamic and the Indian alchemy. This field calls for further studies in order to understand the extent and form of such an interaction.

MERCURY: ITS POWERS

Mercury, extolled by the *rasavādins* as the king of *rasas*, has different names: *pārada*, *rasa*, *sūta*, *mahārasa*, *rasendra*, *svarṇakāraka*, *sarvadhātupati*, and, more significantly, *Śivaja*, *Śivavīrya* and *Harabīja* (seed of Śiva). Further, it has been regarded as the potent agent for bestowing happiness and worldly prosperity on man leading him ultimately to a state of eternal bliss. The *Rasaratnasamuccaya* asserts that 'he who denies mercury, the creative principle of Śiva, will decay in hell age after age'.[b]

The gamut of alchemical literature describes vividly several compositions containing mercury as one of the valuable ingredients. These compositions are presumed to confer an extraordinary longevity and also enable the conversion of base metals into gold. Thus, for example, the sublimate of a composition including mercury, rubbed with an equal weight of gold and admixed with sulphur and borax is said to possess a property by means of which the consumer would develop an imperishable body. Likewise, a composition containing treated mercury has been stated to acquire the power of converting a base metal into a thousand times its weight of gold according to the text, the *Kākacaṇḍeśvarimata Tantra*.[c] The well-known *rasaśāstra* texts abound in elaborate details of transmutation processes involving generally the use of cinnabar, mercury or mercurial ash.

In general, five types of transmutation are mentioned:[d] *lepa* (smearing copper or silver foils with the potent paste of mercury); *kṣepa* (throwing mercury into molten copper or silver); *kunta vedha* (pouring processed mercury into metal to be transmuted); *dhūma vedha* (subjecting the base metal to the action of 'fumes' (of mercury)); and *śabdavedha* (effecting transmutation by the 'impact' (of mercury)). It may, however, be mentioned that there are a few transmutation processes which do not explicitly envisage the use of mercury. Moreover, some of the texts differ from one another in giving the details of the same transmutation process. The

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[a] *Cuṇṇakāṇḍam*, 227, 466.
[b] *RRS.*, 1, 26.
[c] Rāy (P.) (1), p. 150.
[d] *RPS.*, 1, 130–36.

following examples give a glimpse of the nature of transmutation as stated in a few texts. It must be emphasized that the number of transmutation processes mentioned in the texts is very large, and it is almost impossible to give a gist of each of them here.

The *Rasārṇava* gives an account of the conversion of lead into gold as follows: leaves of lead smeared with the paste made of red variety of *karavīra* (*Nerium odorum*) and *manaḥśilā* (realgar) macerated twenty times in tamarind extract, are to be roasted over cow-dung fire into ash. This ash when deposited in a crucible smeared with a paste of one-third part of *rasaka* (calamine), one part of *darada* (cinnabar) and one-fourth of sulphur, realgar, etc., and heated, turns into gold.[a] The same text states that tin could be converted into silver with the help of mercurial ash as follows: one *pala* of mercurial ash, two of tin powder, two of silver ash, five of *śaṅkhacūrṇa* (powder of conch), eight each of common salt and borax, rubbed together and pressed with the milky juice of *Euphorbia neriifolia* is to be roasted fourteen times. Then the whole mass is to be stirred with an iron rod and again heated in a crucible; now it becomes silver. Silver can also be transmuted into gold with the aid of copper.[b] For this purpose, *hema mākṣika* (golden pyrites) and salt are mixed with honey and clarified butter so that the mass becomes red like saffron. It is then subjected to *nāgapuṭa* (a type of prolonged heating). If equal quantities of this treated substance and copper are mixed well and smeared on the leaves of silver, the latter turns into gold. The *Rasaprakāśasudhākara* has a different process in this respect. 'Golden pyrites, *nāga* (lead), *gandhaka* (sulphur), *sūtaka* (mercury), *hiṅgula* (cinnabar), *manaḥśilā* (realgar) and pure gold are powdered and kept in a glass vessel containing the juice of *śāka* (*Tectona grandis*). It is subjected to a type of prolonged heating (*lavanapuṭa*) and then made into a paste. Silver, if treated with this paste, turns into gold.'[c]

According to the *Rasahṛdaya*, silver can be converted into gold by the following method: mercury is to be covered with a powder made of cinnabar, realgar, orpiment, roasted golden pyrites, 'killed' lead and a kind of substance called *kaṅkuṣṭha*, and agitated well with the oil of *kaṅguṇī* (*Celastrus paniculatus*). The mass is heated in steam. If leaves of silver are treated with this composition, they turn into gold of excellent quality. It is stated that the weight of the composition used should be three times the weight of silver. The *Rasahṛdaya* also gives an account of the conversion of bell-metal (*kāṃsya*) into gold. The bell-metal is to be heated with a number of substances, including compounds of mercury and the juice of paddy in a vessel for four months before it acquires the potency of getting transmuted into gold. Copper heated with an equal weight of *tāla* (orpiment) and *vaṅga* (tin) is, according to the same text, turned into silver.[d] The *Suvarṇatantra*[e] gives a detailed account of a bulbous root which exudes a liquid capable of dissolving a needle when pierced into

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[a] *Rṇv.*, **11**, 181–84.
[b] *Rṇv.*, **14**, 121–25.
[c] *RPS.*, **11**, 32–33.
[d] *RHr.*, **18**, 23–69.
[e] Rây (P.) (1), p. 199.

the root. When mercury is rubbed with this bulb in a mortar and then heated in a crucible, it is said to acquire the property of converting a thousand times its own weight of the base metal into gold. Thus the exudate of the bulb is regarded as having extraordinary qualities for bringing about transmutation. Another text, the *Dhātumañjarī*, speaks of a process by means of which mercury, molten sulphur and orpiment, when suitably processed so as to assume the form of fumes, can convert inferior metals into gold.

What happens chemically during the process of transmutation, which is rather a complicated one, cannot be surmised until an experimental verification is attempted from the modern chemical point of view. It would, however, appear that the colour of the inferior metal, say copper or tin, changes into that of the noble metal, gold or silver respectively. The coloration that occurs may be uniform and too intimate enough to expose, under ordinary conditions, the true colour of the inferior metal. The specific gravity and the other normal physical characteristics of the transmuted metal are likely to manifest themselves, as a result of skilful manipulation of the ingredients such as mercury or its compounds, arsenic salts, sulphur, and some quantities of the noble metals themselves. The Indian *rasavādins* knew the distinction between the artificial 'gold' and the real gold. In one of the Tamil texts on alchemy (*Amudakalaijñānam* by Agastya),[a] it has been stated clearly that if the artificial 'gold' (*emam*) and the natural gold (*taṅgam*) are subjected to calcination separately, and the ashes (*bhasma*) so obtained are treated in such a way as to make the 'face' of the metal appear, the difference between the two types of metals can be easily recognized. In other words, the base metal, which has been transmuted, can be converted into its oxide and the latter is reduced to the metallic state again, while the real gold remains unaffected by this method.

Processing of Mercury

One of the important aspects of the *rasavidyā* relates to the eighteen treatments or *saṃskāras* which mercury has to undergo, if it is to exhibit its supreme powers not only as a trusted promoter of long and prosperous life but also to convert base metals into the noble ones. The Indian *rasavādins* adopt the following for this purpose: (1) *svedanam* (steaming or heating using a water bath); (2) *mardanam* (grinding or trituration); (3) *mūrchanam* ('swooning' or making mercury lose its form); (4) *utthāpanam* (also *uddharaṇa*; revival of form); (5) *pātanam* (sublimation or distillation); (6) *rodhanam* or *bodhanam* (potentiation); (7) *niyāmanam* (restraining); (8) *sandīpanam* (stimulation or kindling); (9) *gaganabhakṣaṇam* (also *abhrakagrāsa* or consumption of 'essence' of mica); (10) *cāraṇam* (amalgamation); (11) *garbhadruti* (liquefaction—internal); (12) *bāhyadruti* (liquefaction—external); (13) *jāraṇam* (digestion or assimilation); (14) *rañjanam* (coloration); (15) *sāraṇam* (blending or preparation for transformation); (16) *saṃkrāmaṇam* (acquiring power of transformation);

[a] *Amudakalaijñānam*, v. 1074.

(17) *vedhavidhi* (actual transformation or transmutation); and (18) *śarīra yoga*[a] (becoming fit for internal use).

In some important texts are found elaborate details of these *saṃskāras*. They include rubbing with various plant juices and extracts, incorporation of sulphur, mica, saltpetre, certain alkaline substances, cow's urine and sour gruel. It is indeed very difficult to read exact scientific meanings into these processes which, it is clear, are motivated by an infinite belief in the divine potentialities of mercury. What merits attention, however, is that mercury should be subjected to a series of methodical processes to make it eminently fit for internal use. Mercury from cinnabar is considered to be of good quality, and the first eight of the afore-mentioned eighteen processes are not deemed necessary for it.

Most of the important *rasaśāstra* texts refer invariably to these *saṃskāras* in one way or the other. The *Rasārṇava*[b] mentions eight *saṃskāras* although it makes a reference to four more. The *Rasahṛdaya*[c] and the *Rasaprakāśa Sudhākara*[d] describe the eighteen *saṃskāras* in considerable detail. Briefly the different *saṃskāras* are as follows: *svedana*: consists in steaming mercury in a water bath with a number of vegetable and mineral substances including some salts and alkalis—this process is said to remove the undesirable impurities present in mercury; *mardana*: rubbing steamed mercury in a mortar with vegetable and acidic substances—this process is said to remove some more impurities and thus confer good qualities on mercury; *mūrchana*: rubbing mercury in a mortar with another set of vegetable substances including *kanyā kumārī*, *citraka*, and the three myrobalans, till it loses its own character and form; several unwanted impurities of mercury are said to be removed by this process; *utthāpana*: steaming mercury again in alkalis, salts, the three myrobalans, alum, etc., and then rubbing in sunlight so that the characteristics of mercury are brought into play again; *pātana* (three types, viz. *ūrdhva* (upwards), *adha* (downwards) and *tiryak* (sideways) *pātanas*): rubbing mercury with alkalis, salts, etc., and subjecting to distillation; *rodhana*: mixing the distilled mercury with saline water in a closed pot—this process is believed to restore the 'vigour' or potency of mercury; *niyāmana*: continuation of the process by steaming mercury for three days with a number of plant products, alum, borax, iron sulphate, etc.—this process is said to restrain the motility of mercury; *sandīpana*: steaming with alum, black pepper, sour gruel, alkali and some vegetable substances—this is to 'kindle' the desire of mercury to attain the power of consumption; *grāsa* or *gaganagrāsa*: fixation of the desired degree of the 'essence' of mica for its consumption; *cāraṇa*: boiling mercury with sour gruel, leaves of some kinds of cereal plants, alum, etc., for a week—by this mercury is made to consume mica; *garbhadruti*: treating mercury with other metallic substances so that the 'essences' of the latter become liquefied and thus they may pass through a piece of cloth; *bāhyadruti*: the

[a] *Rṇv.*, **11**, 213–17; *RHr.*, 2.7; *RPS.*, **1**, 12.
[b] *Rṇv.*, **10**, 9–12.
[c] *RHr.*, **2**, 1.
[d] *RPS.*, **1**, 10-12.

'essences' of the minerals or metallic substances to be consumed, becomi molten externally; *jāraṇa*: heating mercury with the desired minerals metals, alkalis and salts so that they are digested and assimilated; *rañjan* a complex process involving the treatment of mercury with gold, silve copper, sulphur, mica and salts in such a way that the former attai different colours; *sāraṇa*: digesting mercury with gold, silver, etc., in a oil-base so as to increase its ability for transformation; *krāmaṇa*: smearin mercury with a number of plant extracts, mineral substances, human mill etc., and then heating with a view to enabling it to possess transmutin powers; *vedhana*: rubbing the treated mercury with oil and a few othe materials so that it results in actual transmutation.

The *rasavādins* believe that mercury, after it has undergone sequen tially the seventeen processes, has all the powers of transmutation. A this stage it should be tested for its powers and, if the test is positive, i should be used for the eighteenth process leading to its assimilation int and rejuvenation of the body.[a]

The *rasaśāstra* texts in which, as stated before, mercury occupies the pride of place, are very important from the point of view of the chemical processes concerning not only mercury but also several other metals and minerals, which they relate in a methodical form. The texts describe these processes in the context of the preparation of various mineral medicines and are thus iatro-chemical in content. They emphasize the effectiveness of the medicinal compositions based on minerals or metallic preparations, used for curing a number of diseases. For our purpose, the classification of substances, processes employed for purification, and methods of preparing different chemical compounds as described in these texts deserve attention.

CLASSIFICATION

The well-known *rasaśāstra* texts like the *Rasahṛdaya*, the *Rasārṇava*, the *Rasaratnasamuccaya* and the *Rasaprakāśasudhākara* have classified the chemical substances into *mahārasa*, *uparasa*, *dhātu*, *ratna* and *viṣa*. There is also a category of substances designated as *sādhāraṇa rasa*. The reason for such a classification is not very clear. According to tradition, the *mahārasas* and the *uparasas* are classified in the order in which they find their usefulness with reference to mercury (*rasendra*). There is also a view that mercury alone has the appellation of *rasa*, and all the others are called *uparasas*. Generally, the *mahārasas*, eight in number, are: *abhraka* (mica), *vaikrānta* (a precious stone having eight surfaces and six angles, probably tourmaline), *mākṣika* (copper pyrites), *vimala* (iron pyrites), *śilājatu* (bitumen), *sasyaka* (copper sulphate), *capala* (a compound of bismuth or

[a] The above information is based on the discussions with Dr. D. S. Joshi, Department of Rasaśāstra, Benares Hindu University, Varanasi; more details of the *saṃskāras* are available in the well-known texts.

selenium) and *rasaka*. The eight *uparasas* are: *gandhaka* (sulphur), *gairika* (red ochre), *kāsīsa* (iron sulphate), *tuvarī* (alum), *tālaka* (orpiment), *manaḥśilā* (realgar), *āñjana* (collyrium; compounds of antimony) and *kaṅkuṣṭha* (probably tinstone or cassiterite).[a] Some of the texts differ from one another in the number of *mahā-* and *uparasas* as well as the substances comprising them. While the *Rasaratnasamuccaya* gives the above classification, another text, the *Rasaprakāśasudhākara*, considers *rājavarta* (*lapis lazuli*) as a *mahārasa* in the place of *capala*.[b] The *Rasahṛdaya*, on the other hand, does not consider mica as a *mahārasa*, but regards *kānta* or loadstone as a *mahārasa*.[c] The *Rasārṇava* includes *darada* (cinnabar) among the *mahārasas* and *rājavarta* among the *uparasas*.[d]

Under the category of *dhātus*, usually seven metals are named: *svarṇa* (gold), *rajata* or *tāra* (silver), *tāmra* (copper), *loha* (iron), *nāga* (lead), *vaṅga* (tin) and *yaśada* (zinc). But, the three alloys (*miśraloha*), viz. brass (*pittala*), bell-metal (*kāṃsya*) and a mixture of five metals (*vartaka*), also come under the category of *dhātu*. Again, some of the texts differ from one another in this scheme. The *Rasārṇava*[e] mentions six metals including copper, while the *Rasaprakāśasudhākara*[f] recognizes copper under the category of 'odorous' metals. On the other hand, the *Rasaratnasamuccaya* does not accord a place to copper among the *dhātus*.

The *ratnas* generally are precious gems. The principal gems used by the *rasavādins* are: *vaikrānta* (also classed under *mahārasa*), *sūryakānta* (sun-stone; aventurine feldspar mainly containing silicate of sodium and potassium with disseminated particles of red iron oxide which cause fire-like flashes of colour), *candrakānta* (moon-stone; a type of feldspar containing silicates of aluminium, sodium, potassium, calcium, barium, etc., which possesses a bluish pearly opalescence), *hīraka* (diamond), *mauktika* (pearl), *garudodgāra* (emerald), *rājavarta* (*lapis lazuli*), *marakata* (topaz), *nīla* (sapphire) and *padmarāga* (ruby).[g] Ruby, sapphire, topaz, emerald and diamond are considered to be superior, as also are pearls of big size and bright appearance. Sun-stone, moon-stone, amethyst, *lapis lazuli*, etc., are referred to as minor gems.

Under the categories of *viṣas* and *sādhāraṇa rasas* a number of plant products and minerals are mentioned, which need only a passing mention here.

'*Purification*' *processes*

The minerals or metals are invariably subjected to purification processes which are rather complicated ones. Though these processes are meant for 'purifying' the substances, more often than naught, some extraneous material is added onto them. In general, purification means, according to the *rasaśāstra* texts, removal of the deleterious principles present in the naturally occurring substances, so that they become fit for internal use.

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[a] *RRS.*, 2, 1; 3, 1.
[b] *RPS.*, 5, 1-2.
[c] *RHṛ.*, 9, 4.
[d] *Rṇv.*, 7, 2, 56.
[e] *Rṇv.*, 7, 97.
[f] *RPS.*, 4, 2, 3; *RHṛ.*, 9, 6.
[g] *RRS.*, 4, 1-3.

There are a good number of such processes in these texts. A few examples may be cited.

Sulphur is purified by melting it in the medium of cow's *ghee* and straining the molten mass through a cloth into milk or the juice of *Bhṛṅga-rāja* kept in a pot.[a] It is then washed with warm water and the process repeated several times. In another process, the mouth of a vessel containing milk is tied with a piece of cloth over which is placed powdered sulphur. This is then covered with an earthen bowl which is heated from outside so that sulphur melts and drops gradually into milk. Purification of sulphur is considered necessary as otherwise the impure sulphur, when taken in, would produce harmful effects such as loss of beauty, strength and vision. Mica is purified by heating it strongly and adding the hot powdered substance into a mixture of sour gruel, cow's urine, decoction of the three myrobalans, cow's milk, etc. The process is repeated seven times.[b] *Vaikrānta* is purified by boiling it with the decoction of *kulattha* (horse-gram). The deleterious principles of *mākṣika* can be removed in the same way. Mercury is purified by rubbing it for three days with the decoction of certain plants like *kumārī* (*Aloe indica*), *citraka* (*Plumbago zeylanica*) and red mustard, or by rubbing it with lime and filtering through a cloth. Thereafter it is again rubbed with some quantity of garlic and common salt, and washed.[c] The gems are purified by subjecting them to the action of the 'vapours' of a plant called *jayantī*. Metals, in general, are purified by heating and subsequently immersing them in butter milk, sour gruel, cow's urine and the decoction of *kulattha*.

Preparations

The *rasavādins* had undoubtedly acquired remarkable experience in the methods of preparing a number of compounds of mercury, and also converting some of the minerals into what is known as *bhasma*. The principal compounds of mercury are *rasakarpūra* (mercuric chloride), *rasapuṣpa* (mercurous chloride), *rasasindūra* (red form of mercuric sulphide), *kajjalī* (black form of mercuric sulphide) and *makaradhvaja* (a sulphide of mercury). Generally the metals and minerals are converted into *bhasmas* for internal use as medicines.

Rasakarpūra is prepared by rubbing pure mercury repeatedly with a salt (*audbhida lavaṇa*) and the juice of *snuhi* (*Euphorbia neriifolia*). It is then taken in a bottle, the outside of which is coated with mud, and heated uniformly on a salt-bed (*lavaṇa yantra*) for a day.[d] A white mass of *rasakarpūra* results. *Rasapuṣpa* is prepared as follows: Purified mercury is intimately mixed with an equal quantity of rock salt and ferrous sulphate (*kāsīsa*) by rubbing the two for a long time. The mixture is then placed in a glass bottle, the outside of which is coated with mud and rag,

[a] *RRS.*, 3, 20, 23–25.
[b] *RRS.*, 2, 17–18.
[c] *Rnv.*, 10, 41–47.
[d] *Rd.SS.*, *jāraṇamāraṇādhikāra*; there are also variations in the use of salt as well as plant juice.

and carefully heated. When the fumes start emanating from the bottle, the mouth of the bottle is closed by a piece of chalk and molasses. The heating is continued for six hours. *Rasapuṣpa* collects at the neck of the bottle as a white substance.

Rasasindūra is obtained by heating an intimate mixture of mercury and sulphur in equal quantities on a sand-bath for about twelve hours. Sulphur in excess goes out as evidenced by the pale blue flame emerging out of the container which is generally a coloured and thick-walled glass bottle, the outside of which is coated as usual with mud and rag. Mercuric sulphide deposits at the upper part of the bottle as a pinkish red substance. *Kajjalī* is the black variety of mercuric sulphide which is obtained by rubbing thoroughly three parts of mercury with one part of sulphur.

The most popular preparation called *makaradhvaja* contains mercuric sulphide and certain stimulants like camphor, pepper and cloves. During its preparation a certain amount of gold is also added.

The preparation of *bhasma* involves considerable skill. Generally, the *bhasmas* are oxides in a finely powdered form. The process is one of incineration of the metallic substance, after the metal or the mineral is treated as desired, usually with sulphur, lime juice or the extracts of certain plants like *kumārī* and *musalī*. The substance is subjected to prolonged heating which is technically known as *puṭa* by means of which the former becomes more and more refined and medicinally potent. The source of heat is the fire of cow-dungs and, depending upon the quantity of the cow-dung cakes used as also the way in which they are heaped, different degrees of heat are sought to be given to the substance. The substance itself is placed in an earthen flat container and enclosed by another, and sealed with mud plaster. The *puṭa-pāka*, as the process is called, is believed to produce extraordinary qualities, both physical and chemical, in the metallic substance, now called the *bhasma*. The *bhasma* is an extremely fine powder, very light and, when thrown on water, just spreads itself as a thin film on it. Several types of *puṭas*[a] are recommended for processing different metallic substances, involving many operational techniques with a view to obtaining the most efficient compositions. For example, in what is known as *mahāpuṭam*, a cubical pit—three feet in length, breadth and depth—is prepared and filled with cow-dung cakes. A crucible containing the substance to be heated is kept covered in the middle of the heap of cakes. When the cakes are set fire to, the process of heating starts and lasts till all the cakes are reduced to ashes. In another *puṭa* called *gaja-puṭam*, the cubical pit is of twenty-two and a half inches in length, breadth and depth. An eighteen-inch cubical pit is called *varāhapuṭam*, and a fifteen-inch one, *kukkuṭapuṭam*. In the place of cow-dung cakes, sometimes husk is also used as a source of fire as in the case of *bhāṇḍapuṭam*. In special cases, solar heat is preferred (*sūryapuṭam*).

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[a] *RPS.*, **10**, 41–54.

Gold is incinerated by first rubbing it with mercury and lime juice, washing it with water and then rubbing with sulphur, and finally subjecting it to *puṭa-pāka* fourteen times. Silver is incinerated by making it an amalgam (with mercury) and the lump thus obtained is rubbed with orpiment, sulphur and lime juice. The mass is then subjected to *puṭa* four times. In the case of copper, the method is more or less similar, only orpiment is not used and the incineration is carried out in a *gajapuṭa* three times. Iron is incinerated using the decoction of three myrobalans and heating it in the *gajapuṭa* at least sixty times. In the case of tin, the juice of *kumārī* is the efficacious additive, and for lead and zinc, the juice of *nirguṇḍi*. These are the general methods followed by the *rasavādins*[a] and there are also variations in the practices adopted by some of them.

The process of 'killing (*māraṇa*)' a metal before it is used as a constituent of medicinal preparations deserves special mention. For this purpose, some salts, copper or iron pyrites, sulphur and plant extracts are used. The best method of 'killing' all the metals, according to the *Rasaratnasamuccaya*,[b] is to heat them with the sulphide of mercury and, according to the *Rasahṛdaya*,[c] with iron pyrites and cinnabar. The 'killed' metal may generally be a sulphide.

Gems are considered to be of special value in the 'fixation' of mercury and also in the preparation of compositions which increase memory and virile power. They are, with the exception of diamond, incinerated by rubbing them with sulphur, orpiment, realgar and the juice of *lakuca*, and subjecting to *puṭa* eight times. The *Rasaratnasamuccaya*[d] gives an elaborate process for the extraction of 'liquid principle' from the gems. Without a proper chemical analysis, it is very difficult to say what would be the chemical composition of this 'liquid principle' which is stated to be the 'essence' of the gem.

It will thus be seen that the Indian alchemists developed processes leading to different alchemical compositions which involve the use of a number of minerals, metals and gems, as also certain medicinal plants which were, by and large, naturally available in India. The details as given in the *rasaśāstra* texts concerning their classification, methods of purification and the like throw ample light on the fact that the Indian *rasavādins* must have arrived at them through protracted experimental methods over a long period. Further, different methods of purification, distillation, extraction of essences and similar other processes could not have been developed without sustained and systematic experimentation which involved the use of the apparatus of various types. This aspect is considered later.

PLANTS IN INDIAN ALCHEMY

An important aspect of the Indian alchemical practice relates to the use of a number of plants in different operations of alchemical and iatro-

[a] Sharma (T. N.), pp. 40-44, [b] *RRS.*, 5, 13. [c] *RHr.*, 9, 16. [d] *RRS.*, 4, 64–69.

chemical nature. The plants are even referred to as *divyauṣadhi* (divine medicinal plants). Generally their roots, leaves or seeds are used in digestion processes. Sometimes oils or exudates of certain plants are also employed. More than two hundred names of plants are mentioned in different texts on *Rasaśāstra* and it is rather difficult to give a complete description of all of them in this short survey. The following is a brief account of some of the plants with particular reference to their iatro-chemical significance.[a, b] *Agasti* (*Sesbania grandiflora*)—purification of *manaḥśilā*, *mākṣika* and *vajra*; *amlavetasa* (*Rumex vesicarius*)—to enable mercury acquire grasping properties, purification and fixation of mercury; *aṅkola* (*Alangium lamarkii*)—purification of mercury; *apāmārga* (*Achyranthes aspera*)—fixation of mercury, calcination of gold and transmutation of mercury into gold; *āsurī* (*Sinapis ramosa*)—purification of mercury; *bhṛṅga* (*Wedelia calendulacea*)—purification of sulphur, realgar, sulphate of iron and collyrium, 'killing' of mercury and iron; *bṛhatī* (*Solanum indicum*)—'killing', restraining and calcining of mercury and 'killing' of iron; *ciñcā* (tamarind)—fixation of mercury, 'killing' of tin, lead and iron; *citraka* (*Plumbago zeylanica*)—'restraining', 'swooning', etc., of mercury and also 'killing' of iron; *devadālī* (*Andropogan serratus*)—for taking essence of metals and *ratnas*, incineration of mercury, etc.; *dhattūra* (*Dhattura fastuosa*)—purification and incineration of mercury, 'killing' of copper and transmutation of silver into gold; *eraṇḍa* (*Ricinus communis*)—transmutation of metals, killing of iron and fixation of mercury; *haridrā* (turmeric)—purification of lead and mercury; *kadalī* (*Musa sapientum*)—purification of *rasas* and *uparasas*; *kanyā kumārī* (*Aloe indica*)—'killing', 'swooning', etc., of mercury, iron and copper, and transmutation processes; *kulattha* (*Dolichos uniflorus*)—extraction of the essence of orpiment, 'killing' of *mākṣika* and purification of mercury and diamond; *musalī* (*Curculigo orchioides*)—'killing', calcining and restraining of mercury; *nimba* (*Citrus acida*)—transmutation processes, fixation of mercury, etc., *niśācara* (*soma*, *Sarcostemma brevistigma*)—imparting to mercury the efficacy of invisible movement, fixation and purification of mercury; *śigru* (*Moringa pterygosperma*)—purification of mercury, *rasas* and *uparasas*; *snuhi* (*Euphorbia neriifolia*)—'killing' of gold, silver and mercury; purification of lead, copper and sulphur, and transmutation processes; *triphalā* (the three myrobalans)—purification of iron and bitumen; *palāśa* (*Butea frondosa*)—transmutation of metals, purification of mercury, 'killing' of mercury, tin and iron; *viṣṇukrāntā* (*Clitoria ternatea*)—fixation of mercury and transmutation process.[c]

The Indian *rasavādins* believed that the minerals and metals would not acquire the desirable iatro-chemical properties unless they were treated or digested with one medicinal plant or the other. Even mercury, extolled as divine, should undergo this process. As the *Mātṛkābhedatantram*

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[a] *Rṛṇv.*, 5, 1–25.

[b] *RPS.*, 9, 1–39.

[c] *See* Appendix for a brief account of the principal chemical constituents of the plants under reference.

emphatically says: 'mercury cannot be reduced to *bhasma* without the help of medicinal plants'.[a]

THE LABORATORY

An estimate of alchemy in India is incomplete without a proper account of the systematic procedures and operations which the Indian alchemists adopted in their pursuit of the Elixir of Life as well as the transmutation of the base metals into gold or silver. Even though alchemy was a common belief among a large section of people in medieval India, the alchemical practices were confined to a limited section of the population. The reason was that the rigours of the faith were as mysterious as they were exacting. Honesty, self-control, sincerity of purpose and, above all, fear of God were considered as very essential for those engaged in the performance of various operations. Besides they were also required to be well versed in the knowledge of minerals and herbs. The mediocres and the dishonest, the quacks and the charlatans could not therefore take to this profession. Instead, the obedient and the faithful who were properly initiated into the secrets of mercurial science of the twenty-seven celebrated alchemists (Ādima, Candrasena, Laṅkeśa, Viśārada, Kapālī, Matta, Māṇḍavya, Bhāskara, Śūrasenaka, Ratnakośa, Śambhu, Sāttvika, Naravāhana, Indrada, Gomukha, Kambali, Vyāḍi, Nāgārjuna, Surānanda, Nāgabodhi, Yaśodhana, Khaṇḍa, Kāpālika, Brahmā, Govinda, Lampaka and Hari, as mentioned in the *Rasaratnasamuccaya*),[b] who were the custodians of the *rasavīdyā* in India, were alone qualified to pursue alchemical practices. In the course of initiation it was enjoined that the 'science of mercury' should be kept a closely guarded secret because it was feared that its efficacy would vanish if divulged to the uninitiated.

The alchemists had their laboratories (*rasaśālā*) too. According to the *Rasaratnasamuccaya*: 'The laboratory is to be erected in a place rich in medicinal herbs. It should be spacious, furnished with four doors and decorated with the portraits of divine beings. It should have several types of apparatus or contrivances. The phallus of mercury (*rasaliṅga*) in the east, furnaces in the south-east, instruments in the south-west, washing operations in the west, and drying operations in the north-west—these and other ingredients necessary for alchemical operations should be installed with chantings. There should be the *Koṣṭhi* apparatus (for extraction of essences) pair of bellows, pestle and mortar, sieves of varying degrees of fineness, earthen material for the crucibles, dried cow-dung cakes for heating purposes, retorts of glass, iron pans, conch-shells, etc.'[c]

The *rasaśālā* or the 'House of mercury and other *rasas*' was a place where the devoted would carry out diverse operations under the benign influence of the *rasaliṅga*, a symbol of esoteric potentiality, which was either a gold amalgam prepared by rubbing gold and mercury (three parts of gold

[a] *Mat.Bh.T.*, **8**, 33–34. [b] *RRS.*, **1**, 2–4. [c] *RRS.*, **7**, 1–21.



FIG. 5.12. The *rasaśālā*—an artist's impression.

and nine parts of mercury) or a compound of mercury and sulphur, shaped into a *liṅga*. The latter has a special significance. The preparation of this type of *rasaliṅga* has been dealt with in the tantrik text, the *Mātṛkābheda-tantram*, in which Śiva tells Devī that mercury is his seed (*bīja*), sulphur her own principle (*svapuṣpa*) and that the *rasaliṅga* is to be prepared with these two constituents. The process consists in intimately mixing mercury with the extract of *jhiṇṭi* (*Barberia cristata*) and constantly stirring (without rubbing) till it assumes the consistency of mud. Then the mixture is shaped into the *liṅga* form and, with the powder of sulphur placed all over the surface, heated slightly over the fire of charcoal or cow-dung. The process is repeated till the *liṅga*, now called the *rasaliṅga*, becomes hard. The *Rasaliṅga* undoubtedly represents a tantrik imagery envisaging a male-female polarity at the divine level, corresponding to the tantrik vision of the highest which is non-dual. In fact, the union of mercury and sulphur in the form of *rasaliṅga* is the non-dual Supreme.[a]

APPARATUS

A number of apparatus and appliances called *yantras* were employed by the *rasavādins*. The crucible, *mūṣā yantra*, was predominantly earthen. To prepare the crucibles, earth of ant-hill, rice husk, iron rust, chalk, human hair and a few other ingredients should be compounded and rubbed together in goat's milk so as to form a dough-like mass which would then be shaped into the desirable forms, and sun-dried. There were various types of crucible for different operations. For the extraction of zinc from calamine, 'a crucible of the shape of *brinjal* (*Solanum melongena*) to which is attached a tubular end which expands towards its mouth like a flower' was generally used. For heating mercury and sulphur together, the following details of a *mūṣā yantra* are given in the *Rasārṇava*:[b] 'The apparatus consists of two crucibles, each twelve digits in length; one of them has a narrow orifice. In this is to be taken sulphur, and mercury in the other. Mercury and sulphur are to be moistened with filtered garlic juice. The sulphur containing crucible is to be inserted into the one having mercury, and the apparatus carefully lowered into an earthen pot over which another earthen pot is to be kept, and the rims luted with cloth. It is heated from outside by cow-dung fire for three days.' Of the other types of crucibles, mention may be made of the *gostanīmūṣā*[c] (crucible of the shape of udder of cow, used for liquefying substances) and the *pakka mūṣā*[d] (a pot-type used for roasting purposes).

In addition to the *mūṣā yantra*, the other types of apparatus mentioned include: *koṣṭhi yantram*, *dolā yantram*, *svedanī yantram*, different types of *pātana yantram*, *dīpikā yantram*, *ḍhekī yantram*, *jāraṇa yantram*, *garbha yantram*, *haṃsapāka yantram*, *kacchapa yantram*, *vidyādhara yantram*, *somānala yantram*, *vālukā yantram*, *lavaṇa yantram*, *nālikā yantram*, *bhūdhara*

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[a] Subbarayappa and Roy, pp. 41–49.
[b] *Rṇv.*, **4**, 8–15.
[c] *RRS.*, **10**, 25.
[d] *RRS.*, **10**, 27.

yantram, puṭa yantram, pālikā yantram, ghaṭa yantram, iṣṭikā yantram, hiṅgulākṛṣṭi, ḍamarkākhya yantram, nābhi yantram, grasta yantram, sthāli yantram, dhūpa yantram, kanduka yantram and the *khalva yantram.*[a, b, c] An attempt is made to give a brief account of some of the important apparatus.

The *koṣṭhi* apparatus consists of two suitable vessels (one of them being bigger) measuring sixteen digits in width and two cubits in length, and both of them having rims on two sides. 'Swooned' mercury is to be placed in the bigger vessel and heated with sour gruel from outside by the application of cow-dung fire from below.

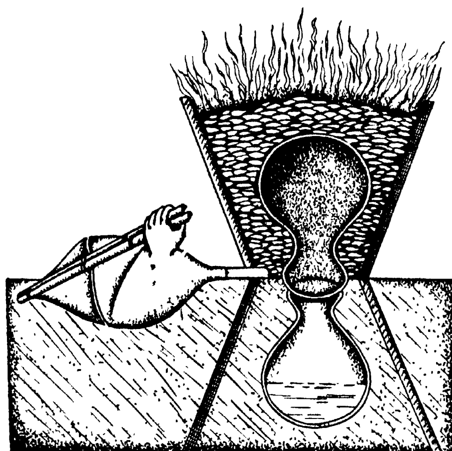


FIG. 5.13. The *koṣṭhi.*

In the *dolā yantram,* the substance is kept in a piece of cloth, tied and suspended by means of a rod which is placed across a pot half-filled with the desired liquid. The substance is kept immersed in the liquid. The liquid is then heated from outside. The *svedanī yantram* is used for steaming purposes. The mouth of a pot is covered with a piece of cloth and the substance to be steamed is placed on the cloth. Water is kept in the pot and this is again covered by means of another pot. The substance is steamed by boiling the water.

The *pātana yantram,* which is employed for purposes of sublimation or distillation, consists of a well-baked pot of suitable dimension. Water is taken in this pot to its neck. Over this pot is kept inverted another big pot. The junction of the two necks of the pots is kept tight by the application of a dough made of lime, raw sugar and buffalo's milk. The inside bottom of the upper vessel is smeared with the substance and it is heated

[a] *Rṇv.*, **4.** [b] *RRS.*, **9.** [c] *RPS.*, **10**, 1–40.

from outside by burning cow-dung cakes. The vapours of the substance fall into the water of the lower one, i.e. sublimation is directed downwards (*adhahpātana*). When necessary, the substance is also heated in the lower



Fig. 5.14. The *dolā yantram.*

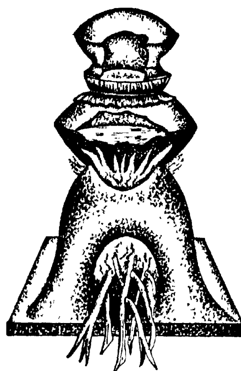


Fig. 5.15. The *svedanī yantram.*

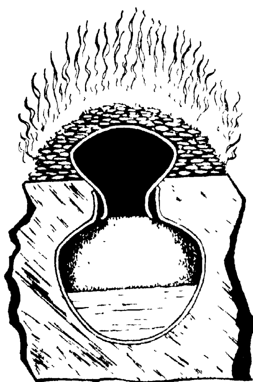


Fig. 5.16. The *adhahpātana yantram.*

pot and the upper one is kept cooled by applying wet rags. The sublimate deposits in the interior of the upper pot, i.e. the sublimation is directed upwards (*ūrdhvapātana*). There is also a variant of this procedure. A pot or a vessel is provided with a long tube fitted in an inclined position, which is in communication with inside of another vessel. The latter serves as the receiver. The substance kept in the former is heated when the vapours condense in the receiver which is kept cooled (*tiryakpātana*).

In another apparatus called the *ḍhekī yantram*, a hole is made slightly below the neck of a pot and one end of a bamboo tube is introduced into it. The other end is fitted into a brass vessel which is filled with water.

Mercury mixed with the other desired substances is subjected to distillation in this type of apparatus. The extraction of mercury from cinnabar is carried out in an apparatus styled the *vidyādhara yantram.* For this purpose, two pots are placed one above the other. The upper one contains cold water and the lower one containing cinnabar is heated.

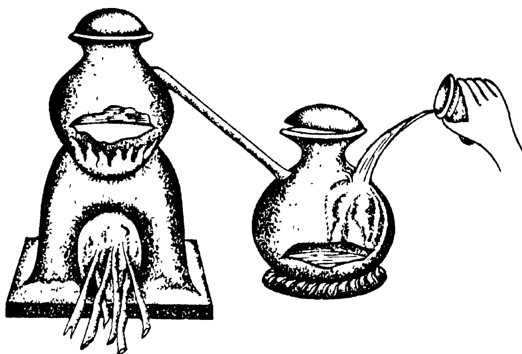


FIG. 5.17. The *tiryakpātana yantram.*

The *vālukā yantram* is of the type of a sand-bath for heating substances uniformly and for usually a long time. A long necked bottle, containing the substance to be heated, is kept buried in sand in an earthen pot up to three-fourths of its height. The apparatus is heated from below for a long time till a straw, when placed on the surface of the sand, catches fire. Instead of sand, sometimes a salt is used, and the apparatus is then called the *lavaṇa yantram.*

Fumigation of the leaves of gold or silver with the fumes of sulphur or arsenic substances is done in another type of apparatus called *dhūpa yantram.* Two vessels are employed for this purpose. In the lower vessel, iron bars are placed in a slanting position below its mouth, and leaves of gold or silver are placed on them. Sulphur or the arsenic substance is placed in the lower vessel and the other vessel is used for covering purposes. On heating, the fumigation takes place. In the *nālikā yantram*, which is more or less of the type of the *lavaṇa yantram*, only an iron tube (*nalikā*) is substituted for the glass bottle. The *bhūdhara yantram* is a simple closed crucible which contains the desired chemical substance and is kept inside a mass of sand. It is heated from outside by burning cow-dung cakes.

The apparatus, it should be noted, are simple and purposeful. Generally they are of earthen material shaped into different forms; but apparatus made of crude glass was also used. The source of heat, either cow-dung or wood, could not yield high temperature. However, the maximum effect of heating was sought to be attained by heating the substances for a long period—from hours to days and weeks.

INDIAN ALCHEMY AND IATRO-CHEMISTRY

Though, as stated before, alchemy appeared late on the Indian scene, it seems to have registered rapid growth. Perhaps in one respect it was far ahead. It seems that in India the use of alchemy for bringing succour to the disease-afflicted humanity was recognized by the *rasavādins* much earlier than the iatro-chemists of the west led by Paracelsus (A.D. 1490–1541). The Indian alchemical texts of even the eleventh or twelfth century A.D. contain details of a number of compositions to be used as medicines for curing specific diseases. The reason is not far to seek. Alchemy in India was concerned more with the life-prolonging processes than with the conversion of base metals into noble ones.

However, one important difference between the iatro-chemists of the west and those of India cannot be overlooked. In the west, the iatro-chemists, in particular Paracelsus, thought that the human body was to be recognized as a chemical system comprising *mercury*, *sulphur* and *salt*. It was further recognized that an imbalance among the three would give rise to diseased states. The third principle 'salt' was introduced by Paracelsus in addition to the already well-known two principles, viz. sulphur and mercury, of the alchemists. This is the famous *triaprima* of Paracelsus.[a] The theory of Paracelsus ran counter to the four humoral theory of the Greeks, of Galen (A.D. 131–201) and Avicenna (*c.* A.D. 980–1037) who were admittedly the two great authorities on medicine in their times. In fact, Paracelsus propounded his theory by burning in public the books of Galen and Avicenna who never considered the human body in chemical terms. The ideas and demonstrations of Paracelsus acted as a stimulus to accept the view that the human body, composed as it is of mineral substances, could, in times of diseased states, be cured by the use of mineral medicines. This eventually pointed to the superiority of the mineral medicines over the herbal ones. According to Paracelsus, alchemy was to engage itself in the noble task of transforming the naturally occurring minerals into products which would prove beneficial to humanity. There came about a view that the diseases were highly specific and, for each such disease, a chemical cure of equal specificity should be found out. Alchemical operations were to be designed towards that end. As against these views, it must be emphasized, the alchemists of India thought of the human body in terms of tantrik elements.

In its earlier state, the Indian *rasavidyā* unlike the *Āyurveda* did not accept the *pañcabhūta* theory or the doctrine of the five elements. At a later stage, however, the postulate that mercury, the principal alchemical element, was itself composed of five elements, gained support. Further, the *tridoṣa* theory which characterizes the *Āyurveda* also came under its purview. In course of time the efficacies of mercury-based medicines were even sought to be formulated in the light of the *pañcabhūta* theory, particularly by the *Siddha* system of medicine in Tamilnadu.

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[a] Mason, pp. 60–65.

In the history of alchemy in India there is still one thread of thought which has not been pursued critically. The *Siddha* system of medicine and practice, mostly followed in Tamilnadu, is known to have mercury-based alchemical ideas relating to longevity. The names of Agastya and Bogar have been mentioned already as the authors of a number of works in Tamil. The writings of Bogar contain a number of references to his contacts with China. Whether he was a Chinese who imparted alchemical knowledge to the Tamilians is a moot point. The Tamilians themselves think of Bogar as having taught alchemy to the Chinese. They believe that one Thirumūlar was the originator of the *Siddha* system. But the date of Thirumūlar has not been established beyond doubt. While tradition places him at about 3000 B.C., the historical evidence assigns to him (Thirumūla-nāyanmār) a date between the sixth and seventh centuries A.D.[a] The name of Agastya is another which is of doubtful authorship as well as date. There appears to be no doubt, however, that the *Siddha* system recognizes the tantrik elements. Eighteen *Siddhas* are generally recognized and of them Agastya and Bogar are the most celebrated. Bogar is stated to have resided on Palni Hills and the disc of mysterious triangles of tantrik significance, which is now there, is attributed to him. In addition, the way the literature on the *Siddha* system speaks of *kuṇḍalinī*, the *cakras*, yogic concentration, *nāda*, *bindu* and the use of mystic letters shows the marked influence of tantrik ideas on this system.

However, there appears to be one important difference between the alchemical ideas found in the Sanskrit texts and those in the Tamil works. In the Tamilian alchemy, a prime substance known as *muppu* occupies an important place. *Muppu* is considered to be the union of three salts, viz. *pūnīru* (possibly a mixture of carbonates), *kalluppu* (rock salt) and *aṇḍakkal* (probably calcium carbonate). Four types of *muppu* are recognized: *vāda muppu*, *vaidya muppu*, *yoga muppu* and *jñāna muppu*. The first type is used in the Tamilian alchemy, the second in the *Siddha* system of medicine, the third and fourth seem to connote their effect on spiritual practices. While the Tamil texts attribute even supernatural powers to *muppu*, the Sanskrit works on alchemy do not speak of *muppu* at all.

It would appear that the Tamilian *muppu* corresponds to the later European concept of the Philosopher's stone, for *muppu* is presumed to possess an extraordinary potency of transmuting baser metals into gold as well as rejuvenating the human system. Even though mercury is given a special place in the *Siddha* system, the former is believed to acquire the desired potency only by the use of *muppu*. In this respect, *muppu* is also referred to as *guru* (the venerable leader) or *guruphaspam*. The *vāda muppu* appears to have in it the compounds (possibly the two chlorides) of mercury.

[a] The Nāyanmārs who were the Śaiva saints of south India flourished from the sixth or seventh century onwards. Thirumūlar, a sixth-century Śaiva yogi, enunciated the doctrine of Pati-Paśu-Pāśam; Majumdar (R. C.), III, pp. 327 ff.

But, to be effective and miraculous, the Tamilian tradition has it that *muppu* should have as its most efficacious ingredient *pūnīru* of very high quality. Even to this day, the practitioners of the *Siddha* system of medicine and believers in alchemy go out in search of *pūnīru* of the best quality. According to the tradition again, there are some 35 places in south India



FIG. 5.18. An efflorescence of *pūnīru*; (inset) *aṇḍakkal*.[a]

where *pūnīru* could be obtained. Kālahasti, Thiru Alankāḍu (near Madras), Śivagaṅga, Paśumalai, Vada Madurai, Dindigal, Thillaivānam, Tenkāsi and Cape Comorin are considered to be among the best places for procuring *pūnīru*. The word *pūnīru* seems to be an outlandish form of *bhū-nīr* or water or exudation from the earth.

[a] The sketch is based on the photograph taken on 2 April 1969 at Thiru Alankāḍu, a place about 40 miles west of Madras, which the author visited for observing the efflorescence between 3 a.m. and 4 a.m. when the fullmoon was low on the western sky. The Siddha Vaidya Dr. T. K. Sivarao accompanied him and gave a practical demonstration of the traditional ways of collecting, grading and later purifying *pūnīru*, in accordance with the well-known texts of the *Siddha* systems.

Pūnīru of the desired quality comes out as an efflorescence (white fluid) from a soil rich in the fuller's earth in these areas during the four full moon nights in the misty months of January, February, March and April. The soil itself is considered in terms of male and female or *bindu* and *nādam* respectively depending upon its appearance, the former being greyish and yielding *aṇḍakkal*, and the latter light grey in appearance. The male-female symbolism is pronounced in the Tamilian alchemy. The principal alchemical substances are even categorized into *āṇṇ* (male) and *peṇṇ* (female). As in the Sanskrit texts, mercury is considered male and sulphur female.

Pūnīru is supposed to be in the nature of male-female union. According to the traditional explanation, *pūnīru* is formed by the action of the rays of the full moon (male) on the earth (female) at certain places. The earth is said to give birth to *pūnīru*. The watery portion found along with the exudation of *pūnīru* is called *amuri* which is supposed to have special medicinal value.

On one of the full moon nights stated above and at selected places, full grown *pūnīru* efflorescence comes up (about an inch in height) and it is collected towards the dawn when the moon is low on the western sky. The top white fluid is carefully taken out, and this is said to be the *pūnīru* of the first quality. The bottom portion along with the sand is also scraped off, and this is considered to be an inferior variety. About a foot below the efflorescence is found the *aṇḍakkal* which is dug out. *Aṇḍakkal*, also called *Bramhakkal*, is egg-shaped and generally brownish or whitish, depending upon the soil.

There seem to be a number of methods of preparing *muppu*, and these methods are kept as closely guarded secrets by the practitioners of the *Siddha vaidya* and alchemy. The three components, viz. *pūnīru*, *kalluppu* and *aṇḍakkal*, are subjected to several processes of purification before they are transformed into *muppu*. A process involving the use of a potent liquid called *muppujeynīr*, consisting of *muppu*, ammonium chloride, chlorides of mercury and sodium chloride, is regarded as of fundamental importance in the Tamilian alchemy. Another liquid called *kaṭijalam* (probably rice gruel) is supposed to be a fluid of great potency even to 'kill' all minerals and metals. The gruel itself is obtained after an elaborate process by prolonged exposure to rays of the sun and moon for a period of six months.[a]

There are two more important aspects of the Tamilian alchemy which deserve special mention. The alchemical substances, minerals and metals, are invariably subjected to complex processes of calcination and the like in order to obtain what are called *bhaspams*, *cendurams* and *cuṇṇams*. Prepared with meticulous care, these constitute different steps even in the transmutation of metals.[b] The other aspect relates to the use of symbolic expressions

[a] Shanmugavelu, pp. 24–46.
[b] This information is based on the discussions with two Siddha Vaidyas of Madras.

for denoting the alchemical substances and processes themselves. In the Sanskrit texts also are found such expressions which go by the name of *sandhyā bhāṣā* (intentional language).[a] The Tamilian symbolic expressions seem to be quite considerable calling for detailed study.

As stated already, the Sanskrit texts give an account of the use of plants in the transmutation processes. The Tamil works also describe similar uses involving different types of plants. The *Agattiyarcarakku* speaks of transmutation processes with reference to a number of herbs. Thus, for example, it is stated that the juicy *vetpanai* (*Wrigutia tinctoria*) is employed in the alchemical process of converting iron into higher metals; the withered *kalthāmarai* (a mountainous plant) is used in processing copper into a higher metal; *vanni* (*Prosopis spicigora*) aids transmutation of iron into copper; *thanninviṭṭan kilaṅgu* (*Asparagus racemosus*) is employed in the alchemical processing of copper; *marudani* (*Lawsonia alba*) and *nirarāli* (*Polygonum barbatum*) help in the transmutation of iron into copper; *serandu pavai* (an unidentified herb) is used in the alchemical process of transmuting iron into copper; *semmaram* (*Soymeda febrifuga*) can be used in the process of transmuting copper into gold; *singaththarai* (an unidentified herb) enables transmutation of iron into gold.

The Tamil texts, which possibly derived inspiration from the Sanskrit sources, appear to deal with certain drug compositions with specific drug actions even outside the pale of alchemy. This is not to suggest that the compositions were totally devoid of undertones of esoteric nature. Nevertheless, there is a significant improvement in the matter of alchemical practices designed towards medicinal formulations for human benefit. A detailed study of Tamil texts relating to the *Siddha* system is essential for understanding the growth and movement of alchemical as well as iatro-chemical ideas and practices in India.

CHEMICAL TECHNOLOGY IN MEDIEVAL INDIA

In the medieval period while the alchemical thought and practice were in the nature of an excursus into the realm of tantrik ideals followed by certain groups of people in some parts of the country, there were many noteworthy chemical techniques which were flourishing at the same time. In this survey particular mention should be made of metal-casting and paper-making. The former found new aesthetic and utilitarian forms and the latter made its début into India in this period.

Metal-working

The metal-smiths in the central, eastern and southern parts of India evolved intricate forms of both copper and bronze images, which were fashioned hollow and solid castings on a large scale by the well-known

[a] Bharati, pp. 164–84.

cire perdue process. A number of bronze images of the Buddha have been recently found in the ruins of a monastery at Sirpur in Madhya Pradesh, and they belong to the ninth-eleventh centuries A.D. The icon-workmanship of metal-smiths in Bengal had considerable influence on the metal-working in Nepal and Tibet.[a] In south India, during the Chola period (ninth to thirteenth centuries) the *cire perdue* solid casting method was generally in vogue. Metal icons were fabricated according to canonically correct ornamentation and in attractive style, aesthetically erecting several figures even on one pedestal.

In this period there came out certain valuable literary works which give details of the icon-making methods. Among them the *Mānasollāsa* or *Abhilaṣitārthacintāmaṇi* attributed to the King Somesvara Bhūlokamalla of the Chalukya Dynasty in the Karnataka area, written in the twelfth century A.D., has given a very clear account of the icon-casting process as follows:

'According to the *navatāla*[b] measurement, as mentioned before, the expert should first prepare the image (i.e. the model) complete with all its limbs, yellowish in colour, beautiful to look at, and with the weapons and arms as prescribed.'

After placing the wax tubes of the length of a *dhatura* flower on the back, on the shoulders and on the neck or the crown (of the image), (the artist) should besmear the image with refined clay.

To clay should be added charred husk, finely rubbed and cotton severed a hundred times and a little finely powdered salt. All these (when mixed with clay) should be ground on a smooth stone and (the paste) should be applied three times all over (the image).

The first layer (of clay) should be transparent (and thin) and dried in the shade. After a couple of days a second layer should again (be applied). When dry again, there should be the third coating thickly applied.

(One) should besmear the whole (image or model) with clay leaving the mouths of the tubes open; and the wise man should dry it (the clay coating) with care and judgement. The expert should first (i.e. before beginning the process just mentioned) measure the wax of the image which has to be made either in brass, or copper, or silver or gold.

Brass and copper should be taken ten times that of wax, silver twelve times, and gold sixteen.

(Then one) should encase the metal, either gold or one that is desired, with clay and coconut-shaped crucible (thus formed) should be dried in the aforesaid manner.

Next, (one) should melt away the wax (from the mould) by heating (the mould) in fire and should afterwards heat the crucible in cinders.

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[a] Reeves, p. 23.

[b] According to this, the entire length of an image is nine times the height of the face, which is generally nine inches; the length of the image is divided into 108 equal parts which are proportionately distributed over the different limbs (Acharya, p. 297).

Brass and copper melt surely with (the help of) cinders just kindled. Silver melts with (the help of) glowing cinders, while gold with (the help of) cinders flaming fivefold.

After making a hole with an iron, on the top of the crucible and holding it tightly with a pair of tongs, (one) should pour molten metal into the mouth of the tube in a continuous stream and stop when it is filled to the brim of the tube.

The adjacent fire should be put out for the purpose of cooling (the mould with the molten metal). When the image gets cooled naturally, the expert should break the clay very carefully.

Then the metal image verily resembles that in wax, endowed with similar limbs and other details.[a]

The icons of the medieval period were indeed noted for their exquisite forms and lasting metallic lustre. The icon production, which was a flourishing metal-art particularly in south India, went hand in hand with the building of imposing temples in increasing numbers. The Vijayanagar empire was noted for brisk trade in a wide variety of bronze objects.

Iron smelting and forging operations were also followed with further achievements. In the temples at Puri and Konark in Orissa are found a number of iron beams. There are as many as 239 iron beams (up to 17′ long and 6″×4″ or 5″×6″ in section) in the garden temple (also called Gunduchiburi) at Puri. The Konark temple contains beams (29 in number) of even larger dimensions (18′–35′ long and about one foot square). A chemical analysis of these beams shows that they are made of wrought iron (iron: 99·64%; manganese: nil; carbon and sulphur: traces; and phosphorous: 0·15%; specific gravity: 7·8) more or less similar in composition to that of the Iron Pillar at Delhi.[b] The probable date of these beams may be about the twelfth century A.D. The Iron Pillar at Dhar (ancient capital of Malwa) is another notable vestige of the medieval period. It is of a much larger size than the Iron Pillar at Delhi, its total length being 43′ 8″. To quote Vincent Smith: 'whilst we marvel at the skill shown by the ancient artificers in forging a great mass of the Delhi Pillar, we must give a still greater measure of admiration to the forgotten craftsmen who dealt so successfully in producing the still more ponderous iron mass of the Dhar Pillar monument with its length of (over) 42 ft.'[c] The Dhar Pillar is now lying broken in three pieces; the largest being 24′ 3″ and square in section. Perhaps the fourth piece is missing. The weight of the pillar is estimated to be about seven tons. While the local tradition maintains that the pillar has been made of the *saptadhātus* (seven metals), the chemical analysis shows that the pillar is made of wrought iron like the Delhi Pillar. As Neogi puts it, 'it must not be forgotten that the Dhar Pillar in its completed condition would be the biggest iron pillar in the whole world.'[d] The date of this pillar is believed to be about the twelfth century A.D. Another

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[a] Reeves, pp. 19–20. [b] Neogi (1), pp. 21–26. [c] Smith (V. A.) (2), p. 145. [d] Neogi (1), p. 30.

iron pillar, probably belonging to the fifteenth century A.D., is that in the temple of Achaleśwar on Mount Abu in Rajasthan. It is 12′ 9″ high with a Śaiva trident on its top. The foregoing achievements amply illustrate how skilful and imaginative were the metal-smiths in India.

In the medieval period, there were many centres famed for making the damascened swords, i.e. those on the surface of which certain patterns like swirls, water ripples and the like are fashioned. Obviously steel of high quality must have been used for making these swords. The blades were etched probably by using some chemicals about which practically no information is available. A microscopic examination of these blades has revealed the dexterity with which the damascene pattern was given to the steel before forging it into blade form. Indian damascened swords were in great demand in foreign countries.

In the Moghul period, there were metallic guns of large dimensions made of bronze and iron. The *great gun of Agra* (made of brass; weight: over 53 tons; length 14′ and bore 22½″) and *Malik-i-maidan* (made of bronze; copper: 80·4%; tin: 19·53%; length: 14′ 3″; diameter: 4′ 10″ at mouth; 2′ 4½″ at bore; probably cast in Ahmednagar and now in Bijapur) deserve special notice. It is believed that the latter was the largest of its type in the world then. The sixteenth century A.D. was specially noted for the production of guns, although it would seem that guns were in use in India even in the fifteenth century A.D. Iron guns of bigger dimensions were also in use, particularly in eastern India, the maximum length of a gun noticed being 31′, and weight about 47 tons. One of the iron guns observed at Dacca (now lost probably in floods) weighed about 30 tons, and the iron ball which it contained had a weight of about 465 pounds.[a]

PAPER MANUFACTURE

While the metal-working had established itself in different parts of the country as an important craft flourishing under indigenous influences, the art of paper-making was introduced into India by about the eleventh century A.D., probably from Nepal which in turn might have obtained the technique of paper production from China. It would also appear that some parts of India, specially western India, obtained the knowledge of paper-making through the Arabs.[b] It seems to be fairly certain that the Chinese knew the method of paper-making as early as the second century B.C. It is believed that one Ts'ai-lun invented the method of producing paper and offered his production as a present to the King in A.D. 105. There is no doubt that the Arabs learnt the process of paper-making from the Chinese, and towards the close of the eighth century A.D., Samarqand and Baghdad had paper factories. By the tenth century A.D. Samarqand had established a reputation for itself for the production of different types of paper.

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[a] Neogi (1), pp. 32–38.

[b] Motichandra, p. 7.

Before the introduction of paper into India, the ancient literature was preserved generally on palm-leaves (*tāla patra*) in south India and birch bark (*bhūrja patra*) in Kashmir and northern regions of the country. But paper began to be used considerably in the fourteenth or fifteenth century A.D. And in the later half of the fifteenth century, Kashmir was producing paper of attractive quality from the pulp of rags and hemp with lime and soda added to whiten the pulp. The Kashmir paper even acquired the status of being an important article of present among the contemporary kings. There were other paper-producing centres in the Panjab (Sialkot), Oudh (Zafarabad), Bihar (Bihar town and Arwal), Bengal (Murshidabad and Hooghly), Gujarat (Ahmedabad), Aurangabad and Mysore. Sialkot produced paper of very high quality in brands such as 'Mansinghi', 'Nimt-tariri' and 'Khasab-i-Jehangiri'. Zafarabad, also known as *Kāghdishaher* (paper city), used to manufacture glossy and strong paper from bamboo pulp, though it was somewhat brownish in appearance. Unpolished paper was also being produced there. Paper from Bihar centres was also very fine. Gujarat, which probably produced the largest quantity of paper in the late fifteenth and the early sixteenth centuries, even exported the Indian paper to the west Asian countries and Turkey. This paper was white, glossy and in all sizes, thick and thin, and in colours. In the Moghul period, Aurangabad developed into an important paper-producing centre and supplied paper to other parts of south India. During Tipu's time, a paper-making factory was started in Mysore where a special type of paper having gold surface was produced by mixing the desired quantity of powdered gold into the pulp before sheeting.

'The technique of paper-making was more or less the same throughout the country differing, of course, only in the preparation of pulp from different materials. The skill of the Indian artisan streamlined the product to greater excellence. Generally the rags were thoroughly cleansed, boiled and beaten into a pulp with water to the consistency of cream. A finely woven wire sieve was dipped into the vat (*daba*). A horizontal shaking motion was given to the sieve, which caused the fibres to felt or interlock, the water draining away through the fine holes in the sieve. The sheet was then placed between felt and subjected to pressure. After drying, the paper was dipped in size (*mandi*) to render it non-porous, and finally dried and smoothened by passing it through rollers under pressure. To size the paper and render it fit for ink, a glue, somewhat gelatinous, was first prepared in the vessel which contained this mixture, a rod was placed and a cleft stick used for holding the sheet of paper during the process of dipping. As soon as the paper had been sufficiently saturated, it was withdrawn by gently rolling it round the stick which had been laid over the vessel. The sheet of paper was afterwards hung to dry. It was then smoothened and polished by rubbing it on wood with the convex side of a chank-shell. Jute, *sunn*, *ambaree*, *moorve*, old sacks and fishing nets were also used as raw materials. Forbes Royle observes that the fibrous parts of many lily and aloe-leafed plants have been converted into excellent paper

in India, where the fibres of tiliaceous, malvaceous and leguminous plants are employed for the same purpose.'[a]

Another method of paper-making was as follows: 'The materials employed were old clothes, old tents, the bark of certain shrubs and trees, etc. ... These materials were beaten with a wooden hammer or *dhenki*, after having been washed well and soaked in water for several days. The pulp was mixed with a little water in a lime-lined (*chunam*) reservoir, where the beating operation was also carried out. The workmen dipped their moulds into the reservoir, and the mixture, when lifted out, instantly would become paper. It was then removed, and each sheet drawn through a second reservoir of water and then hung up to dry. A quantity of gum arabic was dissolved in water into which the beaten pulp was placed. The water in the second reservoir, through which the sheets were drawn, also contained gum in the form of a mucilage, as well as some alum dissolved in it. The moulds or forms used by the workmen were generally made of bamboo. The gum (gum arabic) was obtained as an exudation from a tree, known commonly as the *babool* tree.'[b]

In the late medieval period paper manufacture received great encouragement under the Peshwas, the main centres being Poona, Bijapur, Nasik and Erandol. A chemical analysis of the various kinds of paper of the medieval period has shown that they were principally made of cotton clothes (rags) and flax. Some of them were also made of wood pulp. The ash contents of these paper samples range from 4 to 9%. It would appear that starch or gum was being used for sizing purposes.

COSMETICS AND PERFUMERY

A reference has already been made to the knowledge and practical applications concerning cosmetics and perfumery as contained in Varāhamihira's *Bṛhatsaṃhitā*. In the medieval period, this industry registered considerable progress, and new techniques and compositions were developed. Special texts, both in Sanskrit and in the other languages like Marathi and Kannada, dealing with perfumery and elegant methods of fragrant upkeep of the body, were also composed during this period. Of them, the *Gandhasāra* of Gaṅgādhara (eleventh or twelfth century A.D.) deserves mention.[c] The text gives six processes for the preparation of cosmetics as follows: *bhāvanā* (infusion of fragrant powders with the desired liquids), *pācana* (digestion of materials probably for curing purposes), *bodha* (tempering or intensifying the perfume), *vedha* (further intensification or 'excitation'), *dhūpana* (fumigation with aromatic incenses, vapours, etc.) and *vāsana* (preparation of scents utilizing the perfumes of flowers). Details are given of the *pācana* process in terms of *puṭapāka*, *gartapāka*, *veṇupāka*, *dolāpāka*, *kharparapāka*, *baijayūra* and *kālapāka*. These details throw

[a] Ghori and Rahman, pp. 139–40.
[b] Rây (P.) (1), pp. 234–35.
[c] Gode, I, pp. 297–308; III, pp. 1–12.

ample light on the experimental skill of the perfume-makers. Even to this day some of these processes are in vogue in different parts of the country. The qualitative and quantitative aspects of these processes merit particular attention as they governed the blending, curing or intensification of the perfumes. The *Gandhasāra* mentions twenty-five types of fragrant water (*gandhodaka*) and also a number of fragrant aromatic substances such as *pārijāta*, *mukhavāsa* (perfume to make the breath fragrant), *gandhataila* (scented oil), *yallavāsa* (dust of sandal and pollen of lotus in cold water), *dhūpa* and *varti* (an unguent, eye salve, collyrium or any cosmetic in the form of a ball or pill). Further, the aromatic substances are classified into several *vargas* (categories) in the following way:

(i) *Patra varga* (leaves): *tālisapatra* (*Flacourtia cataphracta*), *jhūla*, *rāmakarpūra* (a species of fragrant grass), *pratāpa* (*Calotropis gigantea*), *tulasi* (holy basil), *murvā* and *damana*;
(ii) *Puṣpa varga* (flowers): *lavaṅga* (cloves), *mucukunda* (*Pterospermum suberifolium*), *campaka* (*Michelia campaka*), *surapuṣpī*, *priyaṅgu* and *śephāli*;
(iii) *Phala varga* (fruits): *marīca* (pepper), *kaṅkola*, *sūkṣmailā* (small cardamoms), *jāiphala* (nutmeg), *reṇukā*, *haritaki* (*Terminalia chebula*), *āmalaki* (*Emblic myrobalan*), *latākasturī* (*Hibiscus moschatus*) and the like;
(iv) *Tvag varga* (bark): *karpūratvak*, *lavaṅgatvak*, *kharjurakauśa*, *aśokatvak*, etc.;
(v) *Kāṣṭha varga* (wood): *candana* (sandal), *agaru* (Agallochum), *raktacandana*, *devadāru*, etc.;
(vi) *Mūla varga* (roots): *puṣkara mūla*, *bhadramustā*, *gandhamustā* and the like;
(vii) *Niryāsa varga* (exudations): *karpūra*, *silhārasa*, *guggula*, etc.; and
(viii) *Jīva varga* (organic): *kastūri* (*Hibiscus abelmoschus*), *nakhī* (*Unguis odoratus*), *sayāla*, *madhu* (honey), etc.

The *Gandhavāda*, the authorship of which is not yet established beyond doubt, is another text (probably fourteenth or fifteenth century A.D.) on perfumery which has a commentary in Marathi of the other texts, the *Agnipurāṇa* (*c.* tenth century A.D.) contains recipes for scented oils. The *utpalagandhi* (lotus-scented saffron coloured oil) is, according to this text, prepared by intimately mixing equal quantities of cinnamon (*tvac*), *murā* (a type of fragrant plant), *Nardostachys jatamansi* (*nalada*) and *Andropagan* (*vālaka*), and then blending the mixture with oil. Similar processes are given for the preparation of jasmine and other scented oils.

There is no denying that India also received the knowledge of preparing some of the perfumes, from outside. The perfume, *ambergris* (*ambara* in Sanskrit), was introduced into India by the Arabs probably in the eighth or ninth century A.D. It was used as *sugandhadravya* or *sugandhaka*. It was also referred to as *mātsyika* by virtue of the fact that this perfume is obtained from the entrails of the whales. Production of

rose water and the *attar* of roses, obtained from the petals of roses (for which Ghazipur in Uttar Pradesh is famous), was a well-known chemical practice in the medieval period. It would appear that the rose itself was introduced into India from Persia through the Arabs, and that the method of extracting *attar* (Arabic word: *itr* meaning perfume) was discovered by the mother of Nurjehan in A.D. 1612. *Āin-i-Akbari* gives a detailed account of the use of rose water in the preparation of perfumes.[a] Akbar was fond of perfumes and *Āin-i-Akbari* speaks of the 'Regulations of the Perfume Officer of Akbar'. The perfume industry received fillip as a result of the royal baths and the religious needs. In paticular, the royal baths were noted for an extravagant use of perfumes, both blended and natural, and this is borne out by the references found in the *Mānasollāsa* of King Somesvara.

GUNPOWDER AND PYROTECHNICS

There is evidence to indicate that guns and gunpowder were in use in Bengal in the beginning of the fifteenth century A.D. It is well known that at the beginning of the Moghul Period (sixteenth century A.D.) gunpowder became an article of warfare. The *Śukranīti,* a Sanskrit treatise attributed to Śukrācārya, gives a description of how the gunpowder can be prepared using saltpetre, sulphur and charcoal in different ratios for use in different types of guns. One such composition, as stated in the text, consists of five parts of saltpetre, one part of sulphur and one part of charcoal, the last to be obtained from the *arka*, *snuhi* and other plants, cleaned and reduced to a fine powder. To the mixture is added the juice of the plants named above and, after thoroughly mixing, it is dried in the sun. It is finally ground into a powder which now becomes gunpowder.[b] *Agnicūrṇa* and *nāḷāstra* are the names given to the gunpowder and gun respectively.

Probably a century or two earlier, Indians possessed the knowledge of manufacturing specific fireworks, since the basic ingredients of the gunpowder constitute the components of mixtures used in the fireworks. By the seventeenth century A.D. fireworks became common in several parts of the country, particularly in Orissa, Gujarat, Maharashtra, Tamilnadu and Kerala. It is believed that the Indians obtained the knowledge of pyrotechnics from the Chinese who had certainly developed pyrotechnics even as early as the eleventh or twelfth century A.D.

The literary sources dealing with gunpowder and pyrotechnics are in Sanskrit, Marathi, Tamil and Malayalam. Of the Sanskrit works, *Kautuka-cintāmaṇi* by Gajapati Pratāparudradeva of Orissa (fl. A.D. 1497–1539), *Ākāśabhairavakalpa* (*c.* fifteenth century A.D.) and *Śukranīti* (*c.* sixteenth century A.D.) are important. Ekanātha's *Rukmiṇisvyamvara* (sixteenth century A.D.) and works of Rāmadāsa (seventeenth century A.D.) are the noted Marathi works, while *Bānaśāstram* and *Bogarsutiram* are well known among the Tamil works. *Vetikkampavidhi* is a manual of fireworks in Malayalam

[a] *Āin* (2), pp. 73–82.

[b] *ŚN.*, 4, 7.

written by one Nilakantha who was also the reputed author of several works on Sanskrit literature. In addition, there is also a treatise on fireworks in Persian, by Zain-ul-Ābidīn, the Muslim King of Kashmir (A.D. 1420-70).

The word '*bāna*' in the sense of a rocket finds a place in the Sanskrit work of Pratāparudradeva mentioned above. The authorship of the important works on pyrotechnics in Tamil is generally attributed to one Bogar or Boganathar who is among the eighteen Siddhas of Tamilnadu and who, according to the local tradition, had contacts with China. The Tamil works on pyrotechnics describe three principal types of fireworks, viz. those which pierce through air (rockets), those which produce sparks of coloured fire, and those which blaze with various colours and end with explosions. Saltpetre, sulphur, charcoal, iron powder, bamboo tubes and flats, mercury, cinnabar, copper salts, camphor, rice paste, arsenic substances, pulp of castor seeds and wicks are among the important ingredients mentioned in these works for the preparation of different fireworks. Several formulae, 98 in number, for the manufacture of some 20 types of fireworks, are found in considerable detail in these Tamil sources. Of particular significance is the fact that the metal dusts (of copper, iron or steel, lead, brass and zinc) are used for producing sparklings of different colours. The date of the works attributed to Bogar is uncertain. On the basis of some internal evidence found in the text, its probable date is twelfth to thirteenth centuries A.D.

Spectacular display of fireworks was a common feature in marriages and other ceremonies in medieval India. In the fifteenth century A.D., various kinds of fireworks were displayed at Vijayanagar during festivals. Even foreign travellers like Barbosa in the sixteenth century A.D. have given vivid descriptions of the display of fireworks in certain parts of India. Bernier has given an account of '*bannes*' in warfare and how they used to be thrown against the enemy as a sort of grenade attached to a stick, and *cherkys*[a] thrown to explode with a view to separating fighting elephants.

CONCLUSION

The foregoing are some of the important technological practices involving the application of chemical knowledge. Though in the medieval period certain technological practices came to India from neighbouring countries, the Indian craftsmen acquired mastery over them soon and even made innovations in course of time. The Indian products like metalware, paper, cosmetics and dyestuffs found preference in foreign markets. There is no doubt that the technicians of medieval India brought to bear their aesthetic sense, too, upon some of their innovations.

Historically, in the West, it was only in the last two or three decades of the eighteenth century that chemistry was placed on a solid foundation.

[a] Gode, II, pp. 1-10, 31-56.

Quantitative experiments were conducted systematically to study the nature of gases like carbon dioxide, air, oxygen, etc. As noted already, Joesph Black (1728-90), Henry Cavendish (1713-1810), Joseph Priestley (1733-1804) and Lavoiser (1743-94) were pioneers in the field of experimentation and methodical interpretation of the observed facts. However, about a century earlier, chemical problems attracted the attention of some leading men of science particularly in England and France, who courageously attempted to offer new explanations of certain phenomena. For instance, they discarded the vitalistic view which was then prevalent, viz. that the inorganic substances were alive, undergoing change as a result of the inner vital forces. Instead, they suggested that external mechanical forces act as instruments of change. This mechanical interpretation was no less responsible for placing the chemical knoweldge on the right path in the latter half of the seventeenth century.

At this time, the British scientist, Robert Boyle, stressed the necessity of interpreting the observations of iatro-chemistry on the basis of the particles of matter and their motion. He advocated the atomic views for explaining such empirical observations as dissolution of salt in water, sulphur in oil or gold in mercury. Further, at that time it was Boyle who gave a precise definition of element as 'certain primitive and simple, or perfectly unmingled bodies; which not being made of any other bodies are the ingredients of which all those perfect bodies are immediately compounded, and into which they are ultimately resolved' (*The Sceptical Chymist*, 1661).[a] Boyle's approach to chemistry was a significant departure from that of either the iatro-chemists or of the alchemists.

In India a mechanistic school of philosophy has been a conspicuous lacuna over a long period of time. It is true that different schools of Indian thought developed the atomic views. These could well have given birth to, and later strengthened a mechanical approach to the interpretation of the observed phenomena and the widely followed practices as well. But the atomism proved no more than a polemical ground. It only became the favourite thinking of the privileged intellectuals.

In brief, it may be stated that the use of minerals, metallurgical practices and processing of common chemicals on the one hand and the craftsmanship associated with them on the other were no less pronounced in India than in the other well-known contemporaneous civilizations. It is no exaggeration to say that in certain technical exercises based on chemical knowledge, India had to its credit notable feats of excellence and outstanding achievements. But they did not receive any support or stimuli whatsoever from the thoughtful and privileged sections of the society. The practices remained more as useful arts than as branches of a developing chemical knowledge. As a result, the technical arts, though engendered from time to time by extraordinary skills and craftsmanship, began to show signs of decay for want of a proper conceptual framework.

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[a] Read, pp. 113-14.

APPENDIX

As noted on pp. 326–27, a number of plants are used in the alchemical or iatro-chemical processes adopted by the *rasavādins*. The present state of knowledge on this subject does not permit yet a critical evaluation of the exact role of these plants *vis-à-vis* the processes associated with them. These plants are used for obtaining several herbal compositions which, in turn, are used as specific cures for certain diseases, by the Vaidyas even now. The following table gives a brief account of the principal chemical constitutents of the plants under reference.

Sanskrit names with botanical equivalents	Principal chemical constituents
1. Agasti (*Sesbania grandiflora* Pers.) ..	bark contains tannin (*a*) and gum.
2. Amlavetasa (*Rheum emodi* Wall.) ..	root contains large proportion of chrysophanic acid, emodin, rhaponticin, tannin, resins (*b*), mucilage (*c*), etc.
3. Aṅkola (*Alangium lamarkii* Thwaites) ..	bitter alkaloid (*d*), alangine.
4. Apāmārga (*Achyranthes aspera* Linn.) ..	fruit yields a large quantity of alkaline ash (potash).
5. Āsurī (*Sinapis ramosa*)	seeds contain oil (25%), sinigrin and myrosin (an enzyme of the sulphatase class).
6. Bhṛngarāja (*Eclipta erecta* Linn.) ..	contains the alkaloid—ecliptine, and resin.
7. Bṛhatī (*Solanum indicum* Linn.)	fruit and root contain wax, fatty acids and the alkaloids—solanine and solanidine.
8. Citraka (*Plumbago zeylanica* Linn.) ..	root contains plumbagin.
9. Dhattūra (*Datura fastuosa* Linn.) ..	leaves contain the alkaloid—daturine (identical with atropine), mucilage, albumen, etc., seeds contain daturine, resin, mucilage, proteids, malic acid, etc.
10. Eraṇḍa (*Ricinus communis* Linn.) ..	seeds contain a toxic substance ricin; oil (ricinoleate of glycerol).
11. Haridrā (*Curcuma longa* Linn.) (turmeric) ..	alkaloid—curcumin, essential oil and resin.
12. Kadalī (*Musa sapientum* Kuntze) ..	ripe fruit contains sugar (22%), starch, vitamins C and B, and some minerals.

	Sanskrit names with botanical equivalents	Principal chemical constituents
13.	Kanyā kumārī (*Aloe indica*) or ghṛta kumārī	aloin (a mixture of glycosides).
14.	Kulattha (*Dolichos biflorus* Linn.) ..	grain with husk contains albuminoids, starch, oil, fibre and phosphoric acid; enzyme urease.
15.	Musalī (*Curculigo orchioides* Gaertn.) ..	resin, tannin, mucilage, fat, starch and ash containing oxalate of potassium.
16.	Nimba (*Citrus acida* or *Citrus bergamia* Ris et Poi)	juice contains citric acid (7–10%), phosphoric and malic acids; and citrates of potassium, sugar, mucilage, etc.; peel contains a volatile oil.
17.	Śigru (*Moringa oleifera* Lam.) ..	bark contains alkaloid and 2 resins; seeds yield oil which is a good source of behenic acid.
18.	Palāśa (*Butea frondosa*, Roxb. & Keon) ..	gum and bark contain kniotannic and gallic acids, soluble mucilage and ash which yield pyrocatechin; seeds contain fat, albuminoids, etc.
19.	Viṣṇukrāntā (*Clitoria ternatea* Linn.) .	root-bark contains starch, tannins and resins; seeds contain oil, resin and tannic acid.

SOURCE: *Indian Materia Medica* by Nadakarni, K. M., revised and enlarged by Nadakarni, A. K., 2 vols., Bombay, 1954.

NOTES:

(*a*) *tannins:* Generally a mixture of polyhydroxy phenolic compounds.

(*b*) *resins:* Contain highly polymerized organic constituents such as oxygen derivatives of cyclic hydrocarbons, terpenoids and phenolic compounds.

(*c*) *mucilage:* Complex organic compounds mainly mixture of polysaccharides and proteins.

(*d*) *alkaloids:* Nitrogen-containing organic bases, characterized by their specific physiological action.

6 AGRICULTURE

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The word 'agriculture' (*agri* = field; culture = tillage) means tillage of the soil leading to production of crops. The origin of agriculture could be traced to the early human attempts at settling down in congenial environments and gradually exploiting the animal and plant resources which were found easily accessible. Undoubtedly, wild plants, their roots, fruits and seeds were among the principal plant resources belonging to the vegetable kingdom used as food by early man. In course of time it is natural to suppose that he must have gained a practical knowledge of their growth-characteristics, factors conducive to their rearing as well as reproduction, and their effect on the human system. There were indeed several steps between the necessity of gathering wild fruits, roots and seeds, and that of the regular cultivation of plants which produce them. When man began to lead a settled life, possibly being assured of an adequate supply of wild plant products some of which he could also store for a reasonable period, he was doubtless in a definite position to indulge in what may be called plant domestication even if it was on a small scale. The archaeological evidence indicates that in the old world the main area of such a domestication of plants was the Near East which is sometimes referred to as the 'Fertile crescent', and which included[a] Mesopotamia, eastern coast of the Mediterranean and the Nile valley. It is now known that by about the eighth or seventh millennium B.C., there were definite practices of plant domestication in the Near East although the beginnings of cultivation occurred at different periods in different places of the region. The digging stick and the hoe were the early contrivances of cultivation and the plough appears to have arrived on the scene by about the fourth millennium B.C. (probably in the eastern Mediterranean region) when agriculture became one of the most important productive enterprises.[b]

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[a] Candolle, pp. 2–3.
[b] *Encyclopaedia Britannica* (edition 1969), pp. 369 ff.

In India, the history of agriculture begins with the practices of the inhabitants of the Indus Valley riparian culture. The fertile alluvial soil, rather a heavy monsoon rainfall at that time and the water of the Indus were conducive to the growth of a number of domesticated plants. As Marshall says: 'Great cities with teeming populations like Mohenjo-daro and Harappa could never have come into being save in a country which was capable of producing food on a big scale, and where the presence of a great river made transport, irrigation and trade easy.'[a] Indeed the economy of the people of the Indus Valley Civilization was based on agricultural produce, which was quite substantial, although it would appear that, when compared with that of Mesopotamia, it was noticeably less. As regards the agricultural implements, they did not know the use of plough, but had only toothed harrow as may be inferred from one of the Indus ideograms.[b] They, however, knew the technique of flood-irrigation.

It has been surmised that a certain jar-type of pottery (called 'scored pottery') might have been used by the farmers of Mohenjo-daro as an appliance for raising water in a manner similar to that of the wheel used in most parts of the Near and Middle East even now. The specimens found at the Mohenjo-daro have deep grooves suggestive of the possibility of their being lashed to a wheel. The base and the rim of this type of pottery are also of shapes suitable to the operation of taking out water. However, in view of the fact that a number of these have been found near small public wells, it has been doubted whether they were used for obtaining a constant stream of water. Mackay says: 'It is more than probable that some arrangement for drawing water for irrigation, by means of an endless rope working on a wheel, with pottery vessels attached to it at intervals, was in use in Sind and other parts of Western India from very early times, though it may not have taken the form of the modern wheel. The latter may have been an improvement introduced into India from Persia. The use of the so-called Persian wheel is almost exclusively confined to Baluchistan, Sind and the Panjab, and some parts of the Bombay Presidency.'[c]

The intensive excavations at Kalibangan, one of the important pre-Harappan sites in Rajasthan, have laid bare a furrowed field showing that even in the third millennium B.C. the technique of agriculture was of a sufficiently developed type.

The querns found in the excavations show how the grinding of the grain was done on an extensive scale. Agriculture in those days mainly comprised cultivation of wheat, barley, sesamum, peas, cotton, date-palm, pomegranate and banana. It is indeed interesting to note that at Mohenjo-daro the wheat unearthed (*Triticum sphaerococcum* or *Triticum compactum*) belongs to a group which is still cultivated in the region of modern Panjab.[d]

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[a] Marshall, I, f.n. 1.
[b] Kosambi, pp. 62–64.
[c] Marshall, I, f.n. 318.
[d] Marshall, I, p. 27.

THE VEDIC PERIOD

In the Vedic period agriculture was an important vocation and the agricultural practices had social and religious undertones even. Domestic (*gṛhya*) rites and festivals then, as now, often synchronized with the four main agricultural operations of ploughing, sowing, reaping and threshing.[a] Some of the *gṛhya* rites also implied the need for maintaining cattle in abundance. That the Vedic people attached great importance to agriculture can be very well understood by the reference made to it in the several hymns. A Ṛgvedic hymn says: 'With the master of the field, our friend, we triumph; may he bestow upon us cattle, horses, nourishment, for by such (gifts) he makes us happy... May the herbs (of the field) be sweet for us; may the heavens, the waters, the firmament be kind to us; may the lord of the field be gracious to us... May the oxen (draw) happily; the men (labour) happily; the plough furrow happily... Auspicious *Sītā* (furrow), be present, we glorify thee: that thou mayst be propitious to us, that thou mayst yield us abundant fruit... May the ploughshares break upon land happily; may the ploughman go happily with the oxen; may Parjanya (water the earth) with sweet showers happily...'[b] Similar ideas are expressed in the *Atharvaveda*[c] which has also a number of hymns which are in the nature of invocation to the god of plenty, of rain and of cattle with a view to getting good harvests and cattle wealth. These reveal that the agricultural practice was regarded as one of noble occupations.

The Vedic word used to denote agriculture is *kṛṣi* which literally means the act of ploughing, the produce being called *sasya*. The Ṛgvedic terms like *yavaṃ kṛṣ* and *sasya* have their identities with the expressions *yao karesh* and *hahya* in the *Avesta*, indicating a possible relation between the agricultural practices of the Vedic India and those of Iran. The agricultural implements mentioned in the Vedic literature include the plough (*lāṅgala*,[d] *phāla*,[e] *sīra*[f] and *sītā*) and *dātra*,[g] *sṛṇī*.[h] *Lāṅgala* was of a lace-pointed type, having a smooth handle, while *sīra* was a large and heavy one. Sieve (*titau*) was in use to separate the grain from the straw, and winnowing (*śūrpa*) was resorted to. *Ūrdara*[i] was the vessel used for measuring the grain.

Plough (*lāṅgala*) was used extensively, drawn by oxen in teams of six, eight or even twelve, and repeated ploughing[j] was resorted to with a view to enabling the soil to acquire the desired quality. The ploughland was called *urvarā* or *kṣetra*. Cow-dung (*śakṛt*) was used as manure and the dried cow-dung (*karīṣa*) was found to be better. The *Kāṭhaka Saṃhitā* describes a process of cultivation as well as harvesting using the plough and sickle[k] respectively. Agriculture was considered by the Vedic people as one of

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[a] *Śat. Br.*, I, 6.1.3.
[b] *ṚV.*, IV, 57.1–3.
[c] *AV.*, III, 17.
[d] *ṚV.*, IV, 57.4; *AV.*, II, 8.4; *Taitt. S.*, VI, 6.7.4.
[e] *ṚV.*, IV, 57.8; X, 117.7.
[f] *ṚV.*, X, 101.3–4; IV, 57.7.
[g] *ṚV.*, VIII, 78.10.
[h] *ṚV.*, I, 58.4.
[i] *ṚV.*, II, 14.11.
[j] *ṚV.*, I, 23.15.
[k] *Kāṭh. S.*, XVI, 10.

reproduction in much the same way as human procreation, as the *Atharva-veda* says: 'Scatter the seeds in the prepared ground (*yoni*).'[a]

Of the important grains grown during the Vedic period, viz. wheat, rice and barley, it is significant to note that the *Ṛgveda* does not mention rice at all. Obviously, then, rice was a wild growth and not yet cultivated in the area in which the *Ṛgveda* was compiled.[b] It began to be grown at a later time as evidenced by the reference to rice in the *Taittirīya*[c] and the *Kāṭhaka Saṃhitās*,[d] and the *Atharvaveda*.[e] The term used for rice of good quality is *taṇḍula*,[f] *vrīhi*[g] and *śāli*,[h] and for the wild variety, *nīvāra*. The *Taittirīya* even refers to the husked (*karṇa*) and unhusked (*akarṇa*) rice.[i]

The Vedic farmers knew the method of improving the fertility of the soil by what may be called the method of rotation. As the *Taittirīya Saṃhitā* mentions, 'rotation of crops' might have been practised inasmuch as rice would be sown in summer and pulses in winter on the same field.[j] According to Roxburgh, the Father of Indian Botany, 'the Western World is to be indebted to India for this system of sowing'.[k] Generally, in the Vedic period two harvests a year were gathered. The common domesticated animals were bull, oxen, sheep, goat[l] and cow. The cow, in particular, was held in high veneration and it even symbolized the mother earth. A Ṛgvedic hymn extols the importance of cow.[m]

The number of references pertaining to agriculture as found in the Vedic literature bring home to us that the cultivator in the Vedic period possessed a fair knowledge of the fertility of the land, selection and treatment of seeds, seasons of sowing and harvesting, rotation and other cultural practices of crops, manuring for increased production of crops, and the like.

As regards irrigation, the Ṛgvedic farmers had realized the importance of constructing channels for carrying water from wells and probably from rivers even. In view of the climatic conditions such as the none-too-heavy annual rainfall, dry air and high temperatures during summer, which would not be conducive to the storage of water, it was not possible to have tanks and other artificial reservoirs, particularly in the Panjab. The principle of collecting water from catchment hilly areas of undulating surface and carrying it through canals to distant areas was also known to the farmers of the Vedic period. Of the water-lifting devices, the *Ṛgveda*[n] mentions one by the name *aśmacakra* which was, as the name suggests, a wheel

[a] *AV.*, III, 17.2. [b] Auboyer, p. 65. [c] *Taitt. S.*, VII, 2.10.2. [d] *Kāṭh. S.*, X, 6.
[e] *AV.*, VI, 140.2; VIII, 7.20; IX, 6.14.
[f] *AV.*, X, 9.26; XI, 1.28; XII, 3.18, 29.30; *Kāṭh. S.*, X, 1; *Ait. Br.*, I, 1; *Śat. Br.*, I, 1.4.3; II, 5.3.4, etc.; *Chānd. Up.*, III, 14.3.
[g] *AV.*, VI, 140.2; VIII, 7.20; IX, 6.14; *Taitt. S.*, VII, 2.10.2; *Kāṭh.*, *S.*, X, 6; XI, 5, etc.
[h] *Śat. Br.*, V, 1.4.14, 3.3.5; *Taitt. Br.*, I, 3.6.7.
[i] *Taitt. S.*, I, 8.9.3. [l] *AV.*, VI, 91.1.
[j] *Taitt. S.*, V, 1.7.3. [m] *ṚV.*, VI, 28.
[k] Majumdar, (G. P.) (3), p. 115. [n] *ṚV.*, X, 101.7.

made of stone; and water was raised, with the help of the wheel, in a pail using a leather strap.[a] Yet another device is referred to as *droṇa*, which was a sloop. There was also a *ghaṭayantra*[b] or *udghāṭana* which was of the type of a drum-shaped wheel round which went a pair of endless ropes with *ghaṭa* or earthen pots tied to them at equal distances. The technical details of all these devices are, however, still unavailable.

THE POST-VEDIC PERIOD

In the post-Vedic period, the political unification which was brought about by the monarchs of Magadha contributed a great deal to the development of agriculture. It must be emphasized that the State then had an established machinery for collecting taxes from its subjects who followed different vocations, the principal ones which provided the people with the means of livelihood being *kṛṣi* (agriculture), *paśupālana* (cattle-tending) and *vāṇijya* (trade). The three together were recognized as *vārttā* (derived from *vṛtti*, meaning livelihood). The most important of the three vocations was, as could be expected, agriculture. The rural economy was based upon the *grāma-kṣetra* (the arable land of the village) which was cultivated not unoften by means of co-operative irrigation. There were also large holdings—estates of 1,000 *karīsas* (probably acres) or even more and one which required for its cultivation as many as 500 ploughs and a number of hired labourers to ply the ploughs with their oxen.[c]

The *Arthaśāstra* of Kauṭilya contains information of value to the understanding of importance of agriculture in those days. Undoubtedly, the State gave considerable encouragement to the settlement of people on unoccupied (*śūnyaniveśa*)[d] land with a view to not only providing them with employment but also increasing the agricultural production. It also supported the construction as well as maintenance of irrigation works and was vigilant so as to ensure continued tilling of the lands,[e] making the act of keeping the fertile land uncultivated, a punishable offence.

In this period there was an increasing awareness of the agricultural properties of the land. With the accumulated experience, it had become possible to classify lands and make attempts to utilize the suitable ones effectively. The land, according to Kauṭilya, consisted of *kṛṣṭa* (cultivated), *akṛṣṭa* (uncultivated), *sthala* (high and dry ground), *kedāra* (field sown with crops), *ārāma* (grovel), *ṣaṇḍa* (horticultural plantations), *mūlavāpa* (field for growing roots), *vāṭa* (sugar-cane plantations), *vana* (forest), *vivīta* (pasture land) and *pathi* (roads).[f]

There was yet another type of land classification from a different standpoint. The growth of medicinal herbs, certain varieties of rice, pulses, oilseeds, etc., which were used for efficient medical care, needed suitable

[a] Raychaudhuri, p. 109.
[b] ṚV., X, 93.12 (Sāyaṇa's interpretation).
[c] Majumdar (R. C.), II, p. 595.
[d] Aś., 2, 1.
[e] Aś., 3, 9.29–38.
[f] Aś., 2, 35; 3, 10.

soil which would be conducive to their efficacy. The two medical classics give details of the distinctive traits of different types of soil commended for the culture of medicinal herbs and certain grains. Suśruta recommends a ground 'which possesses a soil which is glossy, firm, black, yellowish or red and does not contain any sand, ash or any other alkaline substance, is permeable to the germination of seeds and easily pervious to the roots of plants growing thereon, and which is supplied with the necessary moisture from a nearby stream or reservoir of water'.[a] He divides the land into three categories, viz. *jāṅgala*, *anūpa* and *sādhāraṇa*, according to the geographic and climatic conditions. *Jāṅgala* is one which presents a flat surface and has scanty growth of thorny shrubs, isolated hills or knolls, where strong gales of warm wind blow and water gets drained. *Anūpa* is a watery or swampy region with woods and forests, hilly and which is impassable owing to its network of rivers and sheets of accumulated water. *Sādhāraṇa* is midway between the two. A similar type of classification is found in the *Caraka Saṃhitā*.[b]

The *Arthaśāstra*, which throws enough light on the state of agriculture possibly of its time, speaks of the science of agriculture and the Director of Agriculture[c] (*Sītādhyakṣa*). The latter was expected to be conversant with the suitability of the soil, ploughing, preparation of the soil, selection of proper seeds, etc., on the one hand, and the amount of rainfall that was expected to occur in different seasons of the year on the other. The text says: 'In conformity with that, he (the Director) should cause crops to be sown, requiring plenty or little water. *Śāli*-rice, *vrīhi*-rice, *kodrava*, sesamum, *priyaṅgu*, *dāraka* and *varaka* (*Phaseolus trilobus*) are the first sowings. *Mudga*, *māṣa* and *śaimbya* are the middle sowings. Safflower, lentils, horse-gram, barley, wheat, *kalāya*, linseed and mustard are the last sowings . . . which should be in conformity with the season . . . A (region) where the foam strikes (*phenāghātaḥ*) the banks is suited for creeper fruits; (regions on) the outskirts of overflows, for long pepper, grapes and sugar-cane; those on the borders of wells, for vegetables and roots, those on the borders of moist beds of lakes, for green grass . . .'

The *Arthaśāstra* refers to the preparation of the field by ploughing three times (*trīn karṣakān*) in heavy rains.[d] Often deep ploughing was done. The ploughshare which was fitted in the central bent portion (*potra*) of the plough was made of iron.

According to this text, the seeds need treatment before sowing, keeping the seeds (rice, wheat, barley) in the dew (by night) and drying in the sun (by day) for a week would bestow on them the desirable qualities. The seeds of pulses were to be similarly treated for three to five days and nights. Honey, ghee, pig's fat, cow's dung, etc., were also used for treating different seeds. When sprouted, the seeds were fed with fresh acrid fish along with the milk of *snuhi* (*Euphorbia antiquorum*) plant. Though the text does not give details of the method of watering different plants, it significantly

[a] *CS. Sū.*, 37, 1. [b] *CS. Sū.*, 6.7. [c] *Aś.*, 2, 24.11 and 22. [d] *Aś.*, 2, 24.9.

asserts that 'the (farmers) shall pay a water-rate of one-fifth when lifted from rivers, lakes, tanks and wells'.[a] Irrigated cultivation has been classified so as to include flower-gardens, fruit-orchards, vegetables, wet crop-fields and roots.

Pāṇini[b] mentions a practical classification in terms of cultivated and uncultivated lands. The former was known as *karṣa* and the latter included *ūṣara* (waste land) and *gocara* (pasture). The fields were also classified on the basis of the crops grown (*vraiheya* where *vrīhi* was raised; *śaileya—śāli*; *māṣya*—beans; *tilya*—sesamum, etc.) and also the quantities of seed required for sowing (*prasthika*—field sown with a *prastha* measure of seed; *drauṇika—droṇa*, etc.).

There were three crops, one sown in the rainy season and collected in granary in Māgha (January-February), another sown in autumn and collected in granary before Caitra (March-April) and the third sown in spring and stored by Jyeṣṭha (May-June). Two or three crops in a year imply the knowledge of crop rotation. No doubt rotation of crops as a scientific method developed in modern times. Without implying that such a practice was consciously developed with the help of scientific observations, we may say that the knowledge of the requirements of different crops and the different harvest seasons may have led to a rudimentary form of crop rotation. But it must be added that the method had not come into general practice. The cultivator took advantage of the double or triple harvest system or kept the fields fallow depending on the wealth of his fields and as his resources permitted or his needs required. A passage in the *Arthaśāstra* suggesting that for augmenting the finances, the administration could prevail upon the cultivators to raise a second crop indicates that the practice of keeping lands fallow was also resorted to in many cases. The sowing of mixed crops was also widely practised. Patañjali tells us that sesamum was sown with beans (main crop), and the ploughing was done according to the requirements of the main crop. The seeds of the minor crop used to be sown by scattering them here and there.[c]

As a recognition of high position accorded to agriculture by the rulers as well as the people at large, the construction of tanks and other types of reservoirs was considered to be an act of religious merit even. Construction of irrigation works was regarded as one of the most important welfare activities which the State was expected to provide. There are many inscriptions testifying that the rulers honoured this responsibility with devotion. The Maurya monarchs took keen interest in the irrigation schemes. This is borne out by the account of Megasthenes[d] who speaks of a band of officers who 'superintend the rivers, measure the land, as is done in Egypt, and inspect the sluices by which the water is let out from the main canals into their branches, so that everyone may have an equal supply of it'. An irrigation work of historical significance in Saurāshṭra, called Sudarśana

[a] *Aś.*, 2, 24.18.
[b] Agrawala, pp. 195–97.
[c] Agrawala, p. 200.
[d] Abo, XV, 1.50–52.

Lake, was constructed by Puṣyagupta under Chandragupta Maurya and restored later by Tusaṣpa, the Yavana governor of Aśoka. The vast reservoir suffered a breach (420 cubits long and 75 cubits deep) in the second century A.D., owing to heavy flood and onrush of the rivers Suvarnarekha, Palasini, etc., and was repaired by the Parthian *amātya* Suviśākha who was the governor of Rudradāman, the Śaka ruler of that time, at the latter's personal cost.[a] There is no doubt that on this lake depended the prosperity of the people of that area for a long time. In western India the successors of Rudradāman continued the tradition of constructing tanks.

In the central and south India huge tanks of great engineering skill were constructed. The technical skill that went into the construction of these tanks is clear from the fact that some of them even now serve the purpose for which they were made. The pioneer work in this respect was done by Karikala I, who reigned towards the close of the first century A.D., when he tamed the river Kaveri by means of embankments for utilization of the water of the Kaveri through a number of canals. He also excavated tanks for the benefit of those parts of the kingdom which could not receive water from the river. In those days in south India there used to be tank sub-committees of the village assembly, which looked after the maintenance of tanks.

CLASSICAL AGE AND LATER

In the Classical Age and later, agriculture made great headway as indicated by the wide variety of agricultural products grown in different parts of the country, and also the royal encouragement given to irrigation works. The well-organized governments under the Guptas in the Gangetic basin, Malwa, Gujarat and Kathiawar, of the Vākāṭakas and Chālukyas in the Deccan and of the Pallavas in the south took keen interest in, and adopted concerted measures for, the development of agriculture, which led to increased agricultural produce and a flourishing trade in a number of agricultural products. The State had realized the importance of the cultivation of waste lands (*khila*) and so offered liberal terms to the people to purchase them. Land-grants were also made by them on many occasions. The Chinese pilgrim Hiuen Tsang who visited India at this time gives an account of the agricultural as well as horticultural products grown in different regions, such as rice, wheat, ginger, mustard, tamarind, mango, melon, wood-apple, pear, plum, peach and apricot. He even speaks of a variety of rice produced at Po-li-ye-ta-lo (Pāriyātra, i.e. Bairat) which ripened in 60 days.[b] There is no denying the fact that in the period under reference food-grains and fruits were being cultivated on an extensive scale in several parts of the country. A number of literary works of the period, including the encyclopaedic ones, allude directly or indirectly to the agricultural practice as well as the rich produce. While the encyclopaedic

[a] Sharma (R. S.), pp. 95–96.

[b] Watters, p. 300.

ones like the *Amarakośa* and the *Bṛhatsaṃhitā* have in them sections on certain aspects of agriculture, a specific text known as *Kṛṣi Parāśara* deals entirely with agriculture. The contents of the latter may be taken to be as clearly indicative of the then existing knowledge and practice relating to agriculture, such as soil classification and land use, manuring, rotation of crops, irrigation, agricultural meteorology, tillage implements, protection of crops from diseases and pests, care of draught animal and grazing of cattle. The *Kṛṣi Parāśara* asserts: '... one taking to agriculture can become a sovereign monarch in the world. Rice is vitality, rice is vigour too, and rice (indeed) is the means of fulfilment of all the needs (of life). Gods, demons and human beings—all subsist on rice... Blessed is agriculture, holy agriculture and agriculture is the life of creatures... One furrow is conducive to victory, three are the givers of success and furrows numbering five give always crops.'[a]

The text no doubt has portions relating to rites and ceremonies in association with various agricultural operations. Not infrequently superstitious ideas, too, find expression in it. Nevertheless, it must be noted that religious practices of several descriptions were intricately woven into the social fabric of the ancient Indians and, as agriculture was the mainstay of the people, religious rites of superstitious nature were considered necessary in order to be successful in that operation which was, more often than naught, a gamble in rain.

SOIL CLASSIFICATION AND LAND USE

The suitability of different lands for the cultivation of different crops and herbs enumerated in the *Arthaśāstra* and the medical classics respectively has been mentioned already. But the *Amarakośa* describes 12 types of land depending upon the fertility of the soil, irrigation and physical characteristics. The 12 types as mentioned in the *Bhūmivarga*[b] of this lexicon are: *urvarā* (fertile), *ūṣara* (barren), *maru* (desert), *aprahata* (fallow), *śādvala* (grassy), *paṅkila* (muddy), *jalaprāyamanūpa* (watery), *kaccha* (land contiguous to water), *śarkarā* (land full of pebbles and pieces of limestone), *śarkarāvati* (sandy), *nadīmātṛka* (land watered from a river) and *devamātṛka* (land watered by rain). In the *Vaiśyavarga*[c] we are informed of the different kinds of soils particularly fit for the cultivation of different kinds of crops as follows: *kṣetram*—rice and corn; *yavya*—barley; *tailīnam*—sesamum; *maudgīnam*—green gram, etc. There are also different names for lands ploughed once, twice and thrice, and at several stages.

Use of Manure

The *Bṛhatsaṃhitā*[d] prescribes that seeds which have been properly treated are to be sown with the addition of pork or venison into the soil

[a] *Kṛ. P.*, 3–8, 143.
[b] *Amara.*, 5–6, 10–13.
[c] *Amara.*, 6–8.
[d] *Bṛh. S.*, 55, 19–20.

(where previously sesame crop was raised, dug up and trodden) and sprinkled daily with water mixed with milk (*kṣīra*). It says further:[a] 'To promote infiorescence and fructification, a mixture of one *āḍhaka* (64 *palas*) of sesame, 2 *āḍhakas* of excreta of goats or sheep, one *prastha* (16 *palas*) of barley powder, one *tolā* of beef thrown into one *droṇa* (256 *palas*) of water and standing over seven nights should be poured round the roots of the plant.' In order to ensure sprouting and growth of luxurious stem and foliage, according to the *Bṛhatsaṃhitā*,[b] the seed should be soaked in an infusion made of paddy powder, *urad* (*māṣa*), sesame and barley which are mixed with decomposing flesh and the whole mass steamed with the addition of turmeric (*haridrā*). For the growth of *kapittha* (*Feronia elephantum*), the seeds should be soaked for a short time in a decoction of *āsphoṭa* (*Jasmine*), *āmalaki* (*Phyllanthus embellicus*), *dhava* (*Grislea tomentosa*), *vāsaka* (*Justica adhatoda*), *vetula* (*Calamus rotung*), *sūryavallī* (*Gynandropsis pentaphyta*), *śyāmā* (*Echites fructescens*) and *atimuktaka* (*Aganosma caryophyllata*) boiled in milk. The soaked seeds should be dried in the sun and the process is to be repeated for a month. A circular hole is to be made in the ground (1 cubit in diameter and 2 cubits in depth), and the milky decoction poured into it. When it dries up, it is burnt and pasted over with ashes mixed with ghee and honey. Three inches of soil should now be thrown into them along with the powder of bean, sesame and barley, and then again three inches of soil. Finally, washings of fish are to be sprinkled and the mud beaten to a thick consistency. Now the treated seeds should be placed in the hole.[c]

According to the *Agnipurāṇa*,[d] 'a tree becomes laden with flowers and fruits by manuring the soil with powdered barley, sesamum and the offal matter of a goat mixed together and soaked in washings of beef for seven consecutive nights. A good growth of these is secured by sprinkling the washings of fish on them'.

The *Kṛṣi Parāśara* says: 'In the month of *Māgha* a dung heap is to be raised with the help of a spade. When it becomes dried in the sun, smaller balls are made out of it. In the month of *Phālguna*, the dried balls are placed into holes dug for the purpose in the field, and at the time of sowing they are scattered into the field.'[e] The practice of not disturbing the dung heap for a month means the minimization of the loss of nitrogen, the chief fertilizing element, that of drying into balls results in the reduction of active ammonia which may be injurious to the plants, while that of placing the dung balls into pits increases the humus which undoubtedly contributes to the fertility of the soil.

The use of flesh of animals, fish-washings, vegetable products and the farm-yard manure consisting of the excreta of various animals, mixed with litter which would absorb the animal urine, indicates that the farmers of the ancient period were well aware of their fertilizing property and also the

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[a] *Bṛh. S.*, **55**, 17–18.
[b] *Bṛh. S.*, **55**, 26–27.
[c] *Bṛh. S.*, **55**, 22–26.
[d] *Ag. Pu.*, **282**, 11–12.
[e] *Kṛ. P.*, 109–110.

physical effects of the manure upon the texture and water-holding power of the soil, although they did not certainly possess the precise chemical knowledge of these fertilizers. It is now known that the farm-yard manure contains all the essential plant nutrients, viz. nitrogen, phosphoric acid and potash. It is obvious that the knowledge of manuring in those early days was apparently the result of extensive practical observations and not based on the laboratory observations of the modern type.

Agricultural Implements and Accessories

The *Amarakośa* lists a number of agricultural implements such as plough (*lāṅgala*, *hala*), pin of yoke (*yugakīlaka*), shaft of the plough (*lāṅgala-daṇḍa*), goad (*prājana*, *toḍana*), harrow (*kotiśa*), spade or hoe (*khanitra*), sickle (*dātra*, *lavitra*), tie for fastening the yoke to the plough (*yotra*), post for threshing grain on the floor (*medhi*), winnowing basket (*śūrpa*, *prasphoṭana*) and sieve (*cālanī*, *titau*).[a] But it is in the *Kṛṣi Parāśara* that we find a detailed description of the plough. According to this text the plough consists of the following parts:[b] *Yuga* (yoke), *aḍḍacalla* (pins of the yoke), *īṣa* (pole of the plough), *niryola* (rod of the plough exclusive of the pole and the ploughshare), *śaula* (an extra piece of wood that tightly fixes the *niryola* to the pole), *niryolapāśikā* (plates), *halasthāṇu* (strong piece of wood fixed to the *niryola* at the end opposite to where the ploughshare is fixed), *paccanī* (goad made of bamboo with iron top), *abandha* (iron rod which prevents *niryola* from getting out of the pole, *yoktra* (tie) and *phāla* (ploughshare). The text also gives dimensions of some of the parts in terms of plough.

In addition, details are also given of *śṛṇī* (sickle), *khanitra* (hoe), *musala* (pestle), *udūkhala* (mortar), *śūrpa* (winnowing basket), *dhānyakṛt* (winnowing fan), *cālanī* (sieve) and *methi* (threshing post).

Irrigation

As already noted, one of the types of land went under the appelation *nadī-mātṛka* which depended on irrigation utilizing the river water. There is enough evidence to indicate that due recognition was given to irrigation, both natural and artificial. The former channelled the water of the rivers and the monsoons in the northern and north-eastern parts of India respectively and the latter which utilized the stored water in tanks, pools and wells was adopted in the central, north-western and southern parts of India.

The *Nāradasmṛti* states that the erection of dyke in the middle of another man's field is not prohibited in view of the fact that it would be advantageous for irrigation purposes, while the loss is trifling. It states further that a man with the permission of the owner can[c] restore a decayed dyke although without the owner's consent he cannot use it. Nārada

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[a] *Vaiśyavarga*, 12–15, 26. [b] *Kṛ. P.*, 110–17. [c] *Nār. Smṛ.*, 11, 17 and 20.

classifies the dykes into *kheyā* (which is dug into the soil to drain off excess water) and *bandhya* (which is constructed to prevent the water from flowing out).[a]

The State evinced keen interest in the upkeep of irrigation works and even framed rules for their proper functioning. A large number of canals were constructed with a view to not only carrying the water from the rivers or tanks but also preventing the lands from being inundated by swollen rivers. Rightly, therefore, the *Amarakośa* refers to the canals as drains (*jalanirgamaḥ*).[b] In the eighth century A.D. King Lalitāditya of Kashmir got constructed a series of water-wheels to distribute the seasonal flood waters of the Vitasta and the Mahāpadma lakes to various villages and this resulted in the irrigation of the fields. Later in the ninth century, during the reign of Avantivarman, his minister Sūrya constructed a number of dams and irrigation canals which enabled the country to possess abundant agricultural produce.[c]

Reference has been made already to the Sudarśana Lake. When this lake burst again due to heavy rainfall, Cakrapālita, who was the governor of the region, reconstructed it after two months' effort involving huge expenditure. The embankment made was 100 cubits in length, 68 cubits in breadth and seven-man height[d] (about 312 cubits).

Crops

In the Gupta period there were three harvests—summer, autumnal and vernal crops—as mentioned in the *Bṛhatsaṃhitā*.[e] The seeds sown in summer would be duly reaped in *Śrāvaṇa* (early part of autumn) and the harvest was known as autumn crops. The grains sown in autumn yielded vernal crops and those sown in early spring gave the summer crops in *Caitra* or *Vaiśākha*.[f] It is reasonable to suppose that the first two crops were stable crops such as rice and wheat, and the last was of pulses, beans, etc. The rules of cultivation depending upon the season, rainfall, etc., had established themselves and the farmers had the necessary practical knowledge of engaging in agricultural operations leading to the production of a number of grains. A number of crops were grown during this period such as rice, wheat, barley, peas, lentil, pulses, spices and vegetables. Kālidāsa in his *Raghuvaṃśa* refers to paddy being grown in the fields of Bengal.[g] The varieties of rice grown included *śāli*, *kamalā*, *nīvāra*, *uñccha*-paddy and *śyāmāka*-paddy, red rice, yellow rice and hog's rice . . . *Śāli*-paddy was grown as transplantation and this means that the transplantation technique was known to the cultivators. Wheat was grown in the Panjab, Uttar Pradesh, Bihar, central India and Rajasthan, as a *rabi* or winter crop and wherever possible through irrigation. Of the vegetables grown, the

[a] *Nār. Smṛ.*, **9**, 18.
[b] *Amara., Pātālavarga*, 7.
[c] *Rājt.*, **4**, 191; **5**, 69–72, 80–121.
[d] *E.I.*, VIII, 43.
[e] *Bṛh. S.*, **8**, 47; **9**, 42–43; **11**, 2–3; **25**, 2; **27**, 1.
[f] *Bṛh. S.*, **8**,12.
[g] Maity, pp. 80–81.

Amarakośa mentions cucumber, onion, pumpkin and gourd. Sugar-cane was cultivated in the fields where rice used to be grown and harvested generally in winter. Cotton was grown mainly in Saurāṣhṭra or Kathiawar. The cultivation of silk-cotton, flax and hemp was also known. Pepper and cardamom were grown principally in the southern parts of India, particularly in the valleys of the modern Nilgiris. The other spices grown included mustard, cloves, ginger and turmeric. Saffron, betel-nut, tamarind, sesamum, linseed, *priyaṅgu*, aloe, indigo, etc., were also raised. Of the number of fruits grown, mango was the most popular. Coconut was extensively used in the coastal areas of Bengal, Orissa and Madras.

Treatment of Plant Diseases

The *Vṛkṣāyurveda* of Śūrapāla, which is believed to have been written by about the tenth century A.D., gives an interesting account of treating the plant diseases. The diseases of all trees are classified into two groups, viz. (i) those arising from the body, e.g. internal, and (ii) those attacking from outside. The bodily or internal diseases are said to arise from disorders of the wind (*vāta*), phlegm (*kapha*) and bile (*pitta*), while the extraneous ailments are caused by vermin, frost, etc. To indicate some of the well-known methods of treatment mentioned in the text,[a] the relevant translations of the Sanskrit portions are given below:

> 'One should cure the diseases of wind-disorders by the administration of flesh, lymph, fat and *ghee*. Nutriment provided by these substances removes all wind-troubles.
>
> Liberal fumigations with oils in which soap-berry, cow's horn, horse's hair, black pepper, *ghee* and porpoise have been boiled, and the lymph of a hog added, quickly remove the diseases of the wind.
>
> The trees are cured of bilious diseases by being watered with the decoctions of liquorice, honey and *madhuka* and with milk mixed with honey.
>
> All kinds of trees are relieved of bilious diseases if they are watered with the decoction (?) of the three myrobalans in which *ghee* and honey have been mixed.
>
> Insects are destroyed by the administration of water containing milk, carcass, *vacā* and cow-dung, and by the plaster prepared from white mustard, *mustā* grass, *vacā*, *kuṣṭha* and *ativia.*
>
> Fumigation of the tree with the fumes of white mustard, *rāmatha* (?), *viḍaṅga*, *vacā*, black pepper, beef, *ambu* (a kind of Andropogan), horn of buffalo and flesh of a pigeon, mixed with the powder of *lodhra*, at once destroys the colonies of insects infesting the trees.
>
> Plastering with *viḍaṅga* mixed with *ghee*, irrigation with diluted milk for seven days and a poultice of beef, white mustard and sesamum are effective in destroying insects like *kandara* (?).

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[a] Manuscript, Oxford, No. 324 B (Mr. Walkar 137), available in the Bodleian Library, Oxford.

Injury caused by insects is healed by a plaster of *viḍaṅga*, sesamum, cow's urine, *ghee* and white mustard and by watering with milk.

The broken trees are (healed and) restored to health if their fractures are filled with fertile soil, plastered with (the powder of) the barks of *plakṣa* and *udumbara* mixed with *ghee*, honey, wine and milk and then tightly tied with ropes and sprinkled with buffalo's milk and, finally, watered copiously at the roots.

The trees, whose branches have fallen off, would grow branches so abundantly that they would obstruct the view of the sky, if the broken ends of their branches are plastered with honey and *ghee* and they are watered with diluted milk and fumigated.

Trees damaged by fire would cover the sky with foliage, if they are plastered all over with the paste of the lotus-plant and fed with carcass-water.

Trees struck by lightning would bear beautiful leaves, if they are plastered with *vidārī*, sugar, red arsenic and sesamum and watered with diluted milk.'

ANIMAL HUSBANDRY

In the ancient period, a good deal of attention was paid to animal husbandry which included breeding, feeding and maintenance of domestic animals or livestock. Cows and bulls particularly received special treatment. The *Bṛhaspati-smṛti* prescribes severe and cruel punishment for the theft of a cow.[a] The offender was made to lick a ploughshare made of iron having weight of 12 *palas* and heated to redness. If he was not *burnt* in this process, he would be set free. Bulls and bullocks which were employed widely as draught animals were looked after with great care. The *Kṛṣi Parāśara*[b] contains a number of rules of tending the cattle. Practically every village possessed common pasture and woodlands and places of drinking-water for the cattle. Cowsheds were always kept clean and the *Kṛṣi Parāśara* gives directions as to how the shed could be kept clean.[c] According to this text, a shed measuring five by five (?) is good for the healthy growth of cattle and 'the washing of rice, hot scum of the boiled rice, fish broth, cotton seeds and husk, if kept in the cowshed, prove baneful to the cattle'. Incidentally, this gives an idea of the fodder of the cattle at that time. 'To safeguard against the breaking out of diseases, the shed should be occasionally fumigated with vapours of *devadāru* (*Pinus deodara*), *vacā* (oris root), *māṃsī* (pulp of some fruits?), *guggulu* (a fragrant gum resin), *hiṅg* (asafoetida) and mustard seeds mixed together', according to the *Agnipurāṇa*.[d] The *Viṣṇudharmottara*[e] describes certain medical practices of treating the diseased cattle for curing their affected horn, ear, eyes, tooth, tongue, throat,

[a] *Bṛh. Smṛ.*, **10**, 2.
[b] *Kṛ. P.*, 84–88.
[c] *Kṛ. P.*, 89–92.
[d] *Ag. Pu.*, **292**, 33.
[e] *Vi. Pu.*, **2**, 43.1–27.

bladder, etc. The text says that oil in which the pounded mass of ginger, *baṭa* and *jaṭāmāṃsī* has been cooked, and rock-salt and honey added, should be applied to the roots of the horns. The powder of the roots of wood-apple tree, *apāmārga*, *dhātakī*, *paṭala* and *kuṭaja* when rubbed into gums removes toothache. Ginger, turmeric and the three myrobalans are indicated in the cure of sore-throat, and a certain prepared collyrium for the eyes. For the reunion of fractures, *priyaṅgu* mixed with salt is recommended. The bilious disorders are stated to be cured by the administration of cow's *ghee* in which liquorice has been cooked. Ailing calves should be made to drink *pāṭhā* stirred in butter-milk or turmeric dissolved in milk for the alleviation of their suffering. Oilcake in general was considered to be an *elixir* for the cattle. Salt is to be given to the cattle once in 15 days to prevent constipation, colic diseases and loss of appetite.[a] On the whole, animal husbandry was of sufficiently high order in the ancient period.

In the ancient period, agriculture in India, though noted for its extensive and vigorous growth, was not entirely free from conventional practices which sometimes bordered on superstitions and astrological beliefs. Agricultural meteorology, for that matter, was undoubtedly based on conventional knowledge and a good deal of astrological calculations made inroads into it. The rainfall in different seasons of the year was sought to be correlated with the *nakṣatras* or lunar asterisms, and one of the planets was considered to be the presiding deity of the rainfall of the year. The commencement of the agricultural operation, worship of the plough and the animals, auspicious time for harvesting, etc., were conceived in terms of the prevailing planetary influences. Even now, this type of knowledge is current in most rural parts of the country.

While considering agricultural practices in India in the ancient period, there is one important aspect which should not go unnoticed. India for ages has been known for its pithy sayings and proverbs which contain specialized information on various subjects in an epigrammatic style. These are in several Indian languages like Maithili, Tamil, Bengali and Hindi. Many a popular saying has been found in one of the manuscripts on *Vṛkṣāyurveda* and in the *Kṛṣi Parāśara* enshrined in the Adyar Library, Madras. Some of these sayings are given below:[b]

> 'Wheat should be sown in a somewhat dry field and barley in a wet field. If there is heavv rain, then chicken-pea should be sown.
>
> Maize, jowar and millet should be sown somewhat sparesely.
>
> Whosoever sows millet at the intervals of a step, and jowar at the intervals of frog's leap, would be able to fill his barn with the crop.
>
> If the August-September (*Bhadon*) sowing of paddy be done in a field which has been well dug up and prepared (in the month of *Jeṭh*, i.e. May-June), then there would be plenty of rice-flakes (*chinda*) to enjoy.

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[a] *Vi. Pu.*, 2, 43.28.

[b] *Vṛ. Āyur.*, 91–178.

Poppy and linseed should be sown (close) in a wet field.

In one *bighā* of land the following quantities of different seeds should be sown:

Barley and wheat ..	.. 25 seers[a] each
Peas	.. 30 seers
Chicken-peas ..	.. 15 ,,
Maize	.. 2 ,,
Arhar, methi and urad	.. 2 ,,
Cotton ..	.. 1½ seer
Rice	.. 25 seers
Jodhan ..	.. 15 ,,
Sāwan (rice) ..	.. 1¼ seer
Sesamum and mustard	.. A handful each
Barrain and kodan	.. One seer each
Linseed ..	.. 1½ seer
Millet, bajri and sāwan	.. 1½ ,,
Kodan and kakun	.. ½ ,,

A cultivator who sows according to the above proportion would be rewarded with double the crop.

If there be moisture below (in the soil) and clouds above, then the veterans declare that *gerui* disease would be rampant.

If the east wind blows during the month of *Phāgun* (February-March), then wheat crop would be infected with *gerui.*

If the east wind blows in the months of *Māgha* and *Pauṣ* (December-January), then mustard would be eaten away by *mohun* (an insect).

If the south wind blows, how it would be possible to taste the scum of boiled rice (for, there would be no harvest of paddy)?

The *gerui* disease begins when the sun is in the sign of Aquarius (i.e. February-March) and disappears when it is in the sign of Pisces (March-April). It starts from the stalk and eats away the leaves.

If wheat is infected with *gerui* and paddy with *gandhi*, then the cultivator would die of starvation (i.e. want of food-grains).

If in the month of *Māgha* (January-February) the colour of the cloud is red, then surely there would be a shower of hail-stones.

If chicken-pea crop is chilled with cold, then it could be eaten away by the insect called *gadhaita.*

If there is rainfall under the *Citrā* constellation, then the entire harvest would perish.

Under the *Maghā* constellation the locusts thrive and under the *Pūrvā dāṅs* (insects) flourish. But under *Uttara* all these are destroyed.

If there is continuous rainfall day and night, then *sāwan* and *sathi* would be ready for harvesting in 60 days.

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[a] 1 seer = about 2 lb.

> With rainfall under the constellation *Maghā* and food served by the mother, the starving person (would get so much that he) will not have to pray to God for food.
>
> If there be rainfall at the rise of constellation *Citrā* and at the setting of *Hastā*, then the people would not complain howsoever heavily they may be taxed by the king.
>
> If the weather is not sufficiently cold in the month of *Māgha* (January-February), then take it for granted, my friend, that food-grains would become dear (by their prices rising high).
>
> If the south wind blows during the months of *Pauṣ* and *Māgha*, then it is a good sign for (rainfall during) the month of *Sāwan*.
>
> If there is rainfall under the *Maghā* constellation, then all food-grains will have good crop.
>
> If the *Hastā* constellation wags its tail (i.e. sends showers just before setting), then the wheat would thrive without much effort.'

Agriculture as an avowed occupation of the countless Indian peasants flourished with centuries of experience and struggle against the natural oddity in the plains, the hilly tracts and in areas where semi-arid conditions prevailed. With passage of time cultivated areas were on the increase, more rivers harnessed for irrigation and more tanks, wells and other reservoirs constructed. For in the ancient period, Indian economy was intimately interlocked with agriculture.

THE MEDIEVAL PERIOD

In the medieval period, the pattern of agricultural practices was more or less the same as that in early India, save for important changes which were evident in the introduction of new crops, trees as well as certain horticultural plants by the foreign traders and introduction of new land tenure system by the rulers during the period. The geographic distribution of the main food-crops was also more or less the same as we find it today. In respect of irrigation, newer efforts were made to construct canals of great length, and tanks, big and small, in great numbers, the former being noticeable particularly in the north-western part of India and the latter in south India.

An account is given in the chapter on Botany of the principal crops, viz. wheat, rice, barley, millets, pulses, oilseeds, cotton and sugar-cane, and also some of the new plants introduced in this period. It may be noted that the cultivation of cotton was on the increase and that of sugar-cane more widespread in the Mughal times.[a] Bayona region was producing the best indigo, while Malwa and Bihar were known for the production of opium. On the Western Ghats, the cultivation of coffee plants had just begun in the seventeenth century, though the coffee seeds obtained were not of good

[a] Habib, pp. 36 ff.

quality. Western Kashmir was famous for saffron and fruits, the Pandyan kingdom for ginger and cinnamon, Malabar for cardamom and the Malay hills (modern Ootacamund) for the fragrant sandalwood and Kerala, South Canara and Bengal for coconuts. In particular, Kerala was the land of the coconuts and by-products which with salt panned at the seashore paid for the major imports of cloth, metals and even grains. Out of the fibres of the nut ropes were made and used for binding the ships together and also as cables. The kernel found use not only as the main ingredient of a number of sweetmeats but also as a source of oil which was used, as it is now, for lighting purposes and as hair-oil. The other products included charcoal from shell, the trunk of the tree for construction of shelters and houses, fishing boats, etc.

Of the new plants introduced in this period, the cashew (the nut) of South American origin was the most valuable as a money crop then as now. The cultivation of pineapple did not register significant progress, while the potato, guava and custard apple grew better outside Goa where they were introduced first by the Portuguese in the early sixteenth century. About A.D. 1550, the Jesuits of Goa introduced systematic mango-grafting, which improved the Indian fruit out of all recognition and created a further source of income for the horticulturists. Tobacco and chillies (*capsicum*) were also introduced in India in the latter half of the sixteenth century.[a]

In respect of irrigation, wells, tanks and canals continued to be the principal means. In the Upper Gangetic plains and *Dakhiṇa*[b] wells were common. In the Panjab, *arhat* or *rahat* (Persian wheel) was used as a device for lifting water while in the Agra region the *charas*, a sort of a bucket made of leather, was used to lift water with the help of yoked oxen. At places where the water-table was rather high, *denkli*, which was based on the lever principle, was in use. In the south, tanks were constructed in increasing numbers. A Chola king built the Great Anicut (below the island of Srirangam across the river Kaveri) which was a huge dam constructed out of unhewn stone, 1,080 feet long and 40–60 feet broad.[c] There was yet another tank at Porumamilla of greater dimensions—some 6,250 yards long (slightly less than four miles), 83 yards in height and 10 yards broad or wide. This tank was completed in two years probably in the thirteenth century A.D. and we are informed by the Porumamilla tank inscription (A.D. 1291) that there were 1,000 labourers working every day and a fleet of 100 carts were pressed into service to bring the masonry material for the construction of the sluice and the dam. Tank-digging was considered to be one of the greatest meritorious acts in which the king and the people at large took abiding interest. The tank builders exhibited extraordinary skill not only in the construction of tanks but also in the restoration of breaches and distribution of excess of water from tank to tank in times of floods.[d] Wells were also in use for purposes of irrigation and

[a] Gode (P. K.), III, p. 25.
[b] Habib, p. 26.
[c] *Imperial Gazetteer of India*, IX, p. 306.
[d] Appadorai, pp. 204–12.

the water-lifting device employed was known as *ettam*, a type of pulley-wheel with a bucket suspended by rope and worked by hand. In south India the canals were relatively small.

In areas near the sea such as Kerala and Goa, where the country consists of hilly land and the main food-producing soil lies at the bottom of the valley, it was recognized that to prevent water-logging the stream had to be allowed to flow at a rate that would keep the water-table high enough for the cultivation of rice, the only crop grown on such lands. It was also recognized that the salt water from the estuaries should not be allowed to enter at high tide, i.e. dykes must be kept in constant repair, and for this purpose strong flood gates were operated by one or more paid servants. Up some of the streams seasonal clay dykes were built for regulating the water-supply. The land at the bottom of the valley was held in common without fixed partition among the members of the agricultural community. The lower land was separated from the second level by rivetted embankments rising from three to ten feet. The hilltop land was generally held in common for grazing as well as for obtaining firewood. The rest of the land was assigned to the joint families for raising plantation crops. There were also plots for slash and burn cultivation on the sloping hillside. Flat patches on the hilltops provided naturally the soil for cultivation as usual. It may be added that the salt and fish from the sea were mixed with plant ashes and used as fertilizer.

In northern India, the eastern Jamuna canal[a] (which is erroneously attributed to Ali Mardan Khan) was constructed in the early part of the eighteenth century. Shahajahan constructed *Nahr-i-Bihist* or *Shah Nahr*—about 78 miles in length—to meet the water requirements of the new city of Shahajahanabad at Delhi. Yet another canal was constructed during the reign of Shahajahan, and that was from the Ravi at Raipur near the Siwalik hills, which carried water up to Lahore covering a distance of about 84 miles.

Seed-sowing Machine

According to B. A. Keen, formerly Director of the Imperial Agricultural Research Institute at Pusa during 1930-31, India was a homeland of seed-sowing machines. He inclines to the view that the drilling of seeds was practised in India in the eighteenth century and probably earlier. Dr. Anderson of Fort St. George, Madras, remarks that this type of contrivance had been in use from time immemorial. It consisted of a wooden bowl with three or four tube outlets depositing seeds behind the coulters. The bowl was continuously replenished by hand. As there has been no change for years, identically the same type being in use today, it is reasonable to suppose that it was by no means a new contrivance which came on the scene towards the close of the eighteenth century (1796). In the U.K. although the

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[a] Habib, p. 28.

main practices in soil cultivation were well established by 1725, it was only in the first quarter of the eighteenth century that the first practicable implement for sowing of seeds in rows was invented there. This was the system of drilling seed in rows and horse-hoeing in between introduced by Jethro Tull. The first account of it appeared in 1731 in a book entitled *New Horse-hoeing Husbandry* or *An Essay on the Principles of Tillage and Vegetation*. A more comprehensive treatise, *Horse-hoeing Husbandry*, was published in 1753, thirteen years after Tull's death. It is, therefore, reasonable to assume that the seed-sowing machine of India was at least as old as that used in the U.K., if not earlier.

ANIMAL HUSBANDRY

In medieval India, cattle-breeding became one of the professions. While describing the former condition of cattle in India, the *Indian Gazetteer* made references to certain herdsmen as expert cattle-breeders who were conversant with the ways and means of skilfully tending cattle. Even up to recent times, these herdsmen existed in several parts of India, and it is to them that the Report of the Royal Commission on Agriculture (1928) attributes the fine breeds of cattle that are still found in many parts of the Panjab, Gujarat, Mysore, Ongole and Kangayam.

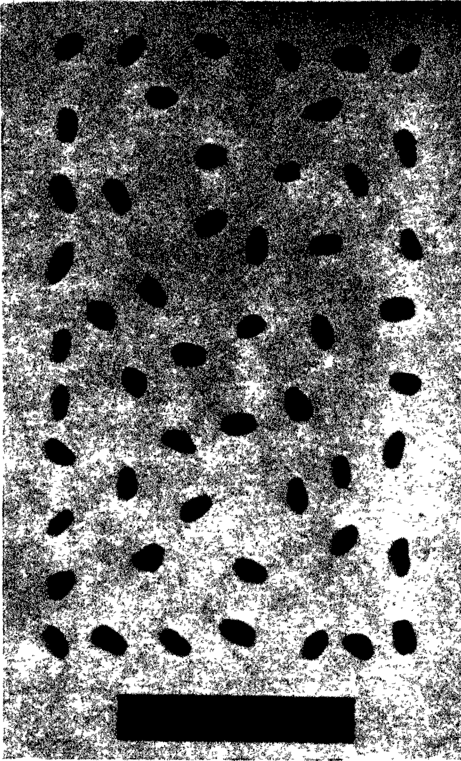
That there has now been a general and all-round deterioration in the cattle-breeds of India requires no elaborate proof, and the causes are not far to seek. Medieval India had to pass through a series of foreign invasions and internal quarrels, and one of the results was that attention to the improvement of agriculture and animal welfare receded to the background. Decrease in the grazing area and the ignorance and poverty of the farmers were also two of the most important factors which have contributed to the present deteriorated condition of the cattle.

STATE AND AGRICULTURE

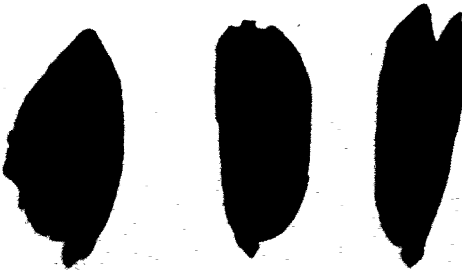
In Sher Shah's reign, in every *pargana* the land was measured after every harvest and revenue collected according to the measurement. The crops of industrious farmers were protected from unnecessary injury by soldiers. During Akbar's time, the cultivators were relieved of a number of taxations, supplementary taxes and fee by which even Hindu rulers had many a time raised the total amount of the land tax above the limit fixed by the constitutional law. The land was classified according to its soil and crop-bearing qualities. One-third of the average produce was collected as land revenue. The taxes were fixed in money value, but every ryot was allowed to pay in kind also, if he thought that the money rate was not fair and if the assessment of his land seemed to him too high, he had the right to insist upon the measurement and division of the crops. A rebate on the full demand was allowed in various cases, e.g. when the land had

suffered from floods or had been out of cultivation for three years. Further, the tax was remitted so long as the land lay fallow. The settlement was first made annually but afterwards for a period of 10 years on the basis of average payments for the preceding term. It is well known that the most important change introduced by Todar Mall was the one in the language and the character used in the revenue accounts to be written in Persian. Todar Mall's *bandobast* or arrangement became a legend in northern India.

PLATE V



Several grains of charred wheat, Mohenjo-daro.
(Courtesy, Archaeological Survey of India, Calcutta.)
See pages 351, 371–72

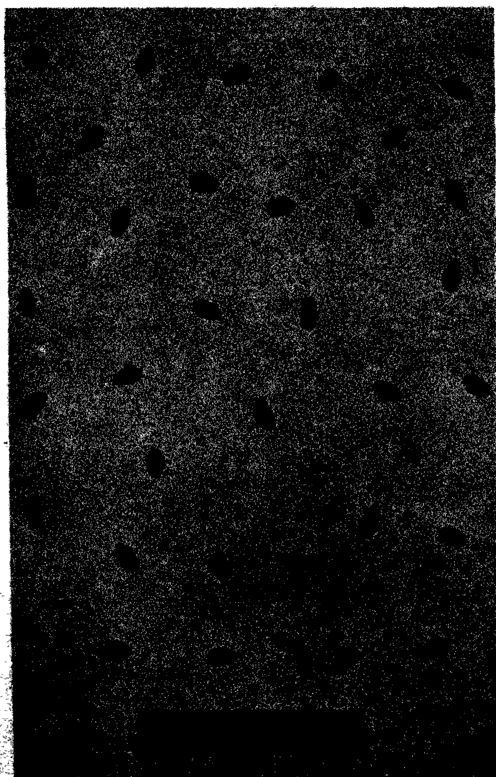




×6 ×10

Rice grains from Atranjikhera, *c.* 2000 B.C.
(Courtesy, Prof. K. A. Chowdhury from his unpublished work.)
See pages 372–73

PLATE VI



Several grains of charred barley, Mohenjo-daro.
(Courtesy, Archaeological Survey of India, Calcutta.)
See pages 351, 371–72

7 BOTANY

PREHISTORIC PERIOD

K. A. CHOWDHURY

THE prehistoric period is many times longer than the historic period. It is now believed that for about half a million years wandering men in small groups lived the life of food-gatherers, taking shelter sometimes in caves and at other times leading a natural life in the open. It was during this period that stone tools were brought into use for the purpose of hunting. This period is known as the Old Stone Age. Some archaeologists believe that wood, a botanical product, was also used along with stone during this era, but actual evidence of use of wood is known only from the late Palaeolithic Age. At this time men of the Clactonian culture in England used yew-wood (*Taxus baccatus* L.) for spear. About the same time an entire spear of yew-wood, as Hawkes and Woolley have discussed, was found in Germany inside the skeleton of an elephant.[a] We can, therefore, say that the oldest record of use of botanical product is from upper palaeolithic era.

India cannot claim the use of botanical products to such an early date. Here our oldest record is from the sites of Indus Valley civilization, in which cereals, woods and other plant products were used. Actual evidence of this sort in India is scanty and scattered and does not allow a chronological history of the uses of plants. It has therefore been planned to give here the history of uses of cereals, cotton and wood alone. The other plant remains have to be kept aside for the time being. A profitable discussion on them will be possible when more data are available.

CEREALS

Wheat and Barley

Among the cereals wheat and barley were recorded from Harappa and Mohenjo-daro. Association of these two cereals in the archaeological remains of Mesopotamia, along with other evidence, has led to the belief

[a] Hawkes and Woolley, p. 156.

that there was some contact between the Indus Valley and Mesopotamian (URS) civilizations. Here Helbaek's opinion is interesting. He has pointed out that these two cereals have been cultivated together from the very beginning of village-farming in West Asia. Luthra has shown that the wheat recovered from Mohenjo-daro belongs to *Triticum vulgare* Vill. (*T. aestivum* L.) and *T. compactum* Host[a] and that from Harappa to *T. compactum* Host and *T. sphaerococcum* Perciv. All these three types of wheat are now put under the Bread or Vulgare group by cytogeneticists.[b] Archaeologists have advanced the hypothesis that wheat originated in South-West Asia and spread over to Europe and North Africa on the one side and to India on the other side via the trans-Caucasian region.[c] Confirmation of this hypothesis is, however, still awaited.

Interesting is also a recent find from western India. Two different types of wheat, namely *Triticum vulgare-compactum* and *Triticum* sp., have been reported by Mittre from the chalcolithic site of Navdatoli-Maheshwar. At present there is no evidence available to show wherefrom this wheat came. When this information is available through scientific investigations of the archaeological plant remains from places lying between those of the Indus Valley civilization and the afore-mentioned chalcolithic site, the significance of the wheat specimen found at the latter place will be realized.

Barley from Mohenjo-daro and Harappa has yielded *Hordeum vulgare* var. *nudum* and *H. vulgare* var. *hexastichum* respectively. The cultivated barley is now classified under two main kinds—two-rowed and six-rowed. These are again grouped under smaller sub-groups based on other morphological characters. Vavilov has suggested the possibility of its centre of origin in two places. Firstly, low-awned and hulled type from Ethiopia and North Africa and, secondly, short-awned, awnless, hullless and hooded type from China, Japan and Tibet. On the other hand, Helbaek holds the opinion that the origin of barley started with wild two-rowed hulled barley (*H. spontaneum*). The cultivated two-rowed barley, hulled and naked (*H. distichum*), directly came from it. From the latter the six-rowed types originated. The cultivated six-row, lax-eared, hulled and naked (*H. tetrastichum*), developed in the plains, while the six-row, dense-eared, hulled and naked (*H. hexastichum*), originated in the mountain region. But the investigation by Chowdhury (K. A.) of remains of barley from Afghanistan does not fit into Helbaek's scheme. It will therefore be seen that the origin of the cultivation of barley still remains to be worked out. When this is done we shall be in a position to say how Indian barley is related to it.

Rice

The origin of rice in India is no less obscure. Some are of the opinion that rice originated in China some 4,800 years ago and came to India later.

[a] Luthra, p. 489.
[b] Chalam and Venkateshwarlu, pp. 180–81.
[c] Hawkes and Woolley, p. 516.

De Candolle did not believe it.[a] The earliest direct evidence of the use of rice in India, as shown by Chowdhury (K. A.), is from Hastinapur, near Meerut—a chalcolithic site (about 3,000 years old). At Hastinapur, only charred paddy was found but also the use of rice-husk as a binder for mud wall of houses. This has raised the possibility of the use of rice in north India much earlier than the age of Hastinapur indicates, because the use of a by-product comes to people when they have made use of the main natural product for a pretty long time. This interpretation is well supported by two written documents. Firstly, rice is mentioned in the *Atharvaveda*. Secondly, āyurvedic literature written by Suśruta recommends rice as cures for certain ailments. All these evidences strongly support the view that rice was used as food hundreds of years before 1000 B.C. Again, occurrences of rice-husk have recently been reported by Ghosh (S. S.) from Gujarat. The age is said to be 2000–1600 B.C. The sites were Lothal in Gujarat and Rangpur in Saurashtra. But Mittre has raised some doubt over this identification because of insufficient material available to Ghosh. It will therefore be judicious to be on the look-out for further evidence of rice from Harappan excavations before we can be sure that it was used as food at that time. Here Mittre's report on rice from the chalcolithic site of Navdatoli-Maheshwar in western India is interesting. He identified these remains as *Oryza sativa* L. This is the first record of ancient rice from south India. We must await more such finds from this part of India before we attempt a profitable discussion on it.

Ragi

Sankalia and his co-workers[b] have excavated a large number of prehistoric sites in south India. In course of their investigations they found out ragi (*Eleusine coracana* (L.) Gaertn.) at a site of 2000 B.C. The origin of ragi is said to be Indian. Many more sites of ancient ragi have to be located before we can confirm the belief that ragi originated in India.

COTTON

Cotton (*Gossypium* sp.), a commercially important plant product of the present century, can be traced back to Indus Valley civilization. From Mohenjo-daro, fragments of cotton cloth and string were recovered. Microscopic examination by Gulati and Turner of these fragments led to their identification as lint from *G. arboreum* which is now extensively grown in India. Researches on the origin of old world cotton are interesting in this context. In 1947, Hutchinson, Silow and Stephens put forward the hypothesis that cultivated cotton arose in the Indus Valley but later Hutchinson[c] has rejected it and suggested an alternative area in Africa. Much earlier, Watt[d] pointed out that India derived some of its original stock of cotton

[a] Chalam and Venkateshwarlu, p. 180.
[b] Sankalia (2), pp. 28–40.
[c] Hutchinson (J. B.), p. 225.
[d] Watt, pp. 193, 321.

from Africa. Work in this direction is being continued. Recently a few cotton seeds with lint and fuzz have been discovered at an excavation at Nubia, Egypt. Microscopic examination has shown its resemblance to *G. herbaceum* group. From these facts it will be seen that much research will be necessary before the origin of present-day cotton is finally determined.

As regards written information on cotton, Brown[a] has drawn attention to its first reference in the *Ṛgveda*. Later, religious books of Manu also mention cotton. Greek writers, Herodotus and Theophrastus, report about cotton which comes from fruit of some wild trees in India. Indians not only grew cotton but also devised methods of ginning, spinning and weaving it into clothes. Despite the primitive nature of the gears, the final product was excellent and admired by foreigners who visited the country during early centuries.

WOOD

The oldest record of use of wood, in the Indian region, is from Harappa proper and from sites of Harappan culture in Gujarat. In the former two woods were found to have been used from a coffin, namely deodar (*Cedrus deodara* Loud.) and rosewood (*Dalbergia latifolia* Roxb.). Both are well known for the scent that they give off. Other wood remains found here and examined by Chowdhury and Ghosh (1) were used for a wooden mortar (*Zizyphus mauritiana* Lamk. Syn. *Z. jujuba* Lam. non Mill.) for pounding grains. Choice of these woods for specific purposes shows not only knowledge of where the trees grow but also of the characteristic qualities of the woods used. Here is a strong evidence to show that Harappan culture was based on years of experience on the use of this botanical product. The charred timbers recovered from Lothal in Gujarat and studied by Rao and Lal were *Acacia* sp., *Albizzia* sp., *Tectona grandis* L. f., *Adina cordifolia* (Roxb.), Benth. and Hook., *Soymida febrifuge* A. Juss. This is a clear indication that the Harappans knew of the quality of these timbers nearly as much as we know of them today.

Of the old wood, special mention should be made of the two largest remains of wooden tools and implements which have been found at Burzhom in Kashmir and Chirand in Bihar, belonging to the neolithic complex of these sites. These remains indicate the various types of trees and plants which were used by the neolithic people of those areas.

The other plant remains of later age are *Dalbergia sissoo* Roxb. and *Holarrhena antidysenterica* Wall. from Hastinapur, a chalcolithic site; these were used as firewoods (Chowdhury and Ghosh (3)). Near about the historic period (2,000 years) at Pataliputra a wooden palisade was put up as a protective measure against erosion by the River Ganges. The wood piles were of sal (*Shorea robusta* Gaertn.), one of the most

[a] Brown, p. 2.

durable timbers in India, when used in contact with soil. The quality of the wood of the piles was estimated to be one of the best that sal can produce (Chowdhury and Ghosh (4)). For a gate at Sisupalgarh the timber used was *Acacia* sp. (Chowdhury and Ghosh (2)). An analysis of the use of all these wood remains invariably gives the impression that prehistoric men possessed sufficient sound knowledge of the properties of wood to make good use of them.

Now coming to ancient literature, there are many instances of reference on the uses of wood. Occasionally, instructions regarding timbers to be used for various purposes were also given. When an analysis of these instructions is made, one gets the impression that basic knowledge on the seasoning properties of wood was available at that time. For the first time mention is also made of the craftsmen called *vaddhaki* who worked with wood.

Thus it will be seen that the people of India had acquired a sound knowledge of the properties of wood and its efficient utilization even about 5,000 years ago. If the people of Vedic Age can be credited with the practices of the rotation of agricultural crops, the credit of woodworking certainly belongs to a people of a much earlier age.

THE VEDIC AND POST-VEDIC PERIOD

A. K. Ghosh *and* S. N. Sen

THE VEDIC PERIOD

If the prehistoric period furnished evidence of the cultivation of cereals like wheat, barley, rice and ragi and of the use of woods of several varieties, it would be too natural to expect to find references to them in the literary records of the early historic period characterized by the composition of the *Saṃhitās*, the *Brāhmaṇas* and the *Āraṇyakas-Upaniṣads.* These records indeed bear ample testimony to the development of agriculture as an important factor in the Vedic economy. The *Ṛgveda* has frequent references to the use of the plough, the sowing of seeds, the cutting of corn with the sickle, the threshing and winnowing of the corn, the practice of channel irrigation and the like. Agricultural pursuits definitely made further progress in the later phase of the Vedic culture as is evidenced by the use of larger and heavier plough, mention of several types of agricultural produce such as wheat, beans, corn, sesamum, extraction of oil from sesamum, relationship between seasons and the harvest, plant diseases and some attempt to deal with them with magical spell. The growing acquaintance with plant life is further reflected in the appreciation of the medicinal properties of plants and in the appearance of a class of Atharvan priests specializing in the herbal treatment of diseases. Of no less importance is the diversification of the industrial life witnessed during this

period, in which a number of industries were clearly based on agriculture, e.g. basket-making, rope-making, dyeing, chariot-making, and so on.

BOTANICAL KNOWLEDGE CONTAINED IN THE *SAṂHITĀS, BRĀHMAṆAS AND UPANIṢADS*

What glimpse, if any, of the development of a kind of plant science do we obtain from such literary records as also from the bulk of the ritualistic materials in which the *Saṃhitās*, the *Brāhmaṇas* and the *Āraṇyakas-Upaniṣads* abound? The main difficulty lies in the scattered nature of the materials bearing on plants, as on several other matters of scientific interest, in these sacerdotal texts. Botany as a systematized branch of knowledge had not yet developed, and its evolution as a subject of specialized interest did not take place until after a much later date. Nevertheless, by arranging and regrouping these scattered materials under meaningful heads in which it is now customary to describe the plant science, it is possible to get a fair idea of the Vedic Indians regarding the morphology and internal structure of plants, their physiology and also whether at such distant date any attempt was made at their classification.

As to morphology, different parts of a plant body such as the root, the shoot, stems, branches, leaves, flowers and fruits are distinguished and clearly named in the *Saṃhitās*, *Brāhmaṇas* and *Upaniṣads*. The *Ṛgveda* uses the term *skandha* for the trunk or corona of the tree. The *Taittirīya* and the *Vājasaneyī Saṃhitās* enumerate the parts of a plant body as *mūla* (root), *tūla* (shoot), *kāṇḍa* (stem), *valśa* (twig), *śākhā* (branch), *parṇa* (leaf), *puṣpa* (flower) and *phala* (fruit).[a] In the well-known hymn of the *Atharvaveda*, dealing with medicinal plants, similar descriptions of plant bodies are met with.[b] The plants are differently coloured—brown (*babhru*), white (*śukra*), red (*rohiṇī*), black (*kṛṣṇa*), spotted (*pṛśni*) and swarthy (*asiknī*). They are also of different types; some are of the spreading variety (*prastṛṇatī*), some bushy (*stambinī*), some jointed (*kāṇḍinī*), some rich in shoots (*aṃśumatī*), some singly calyxed (*eka-śuṅgā*), some plants have spreading branches (*viśākhā*) and some by nature tend to extend (*pratanvatī*). The different parts are referred to as follows:

> 'Honied are the roots of these herbs, honied their tops, honied their middles, honied their leaves, honied their blossoms...'
>
> 'Those that have flowers, those that have blossoms, those that bear fruit and those that are without fruit...'[c]

It is futile to expect any detailed knowledge of the internal structure of plants, but some gross anatomy of the plant body is indicated in the

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[a] *oṣadhibhyaḥ svāhā mūlebhyaḥ svāhā tūlebhyaḥ svāhā kāṇḍebhyaḥ svāhā valśebhyaḥ svāhā puṣpebhyaḥ svāhā phalebhyaḥ svāhā | vanaspatibhyaḥ svāhā mūlebhyaḥ svāhā tūlebhyaḥ svāhā skandhobhyaḥ svāhā śākhābhyaḥ svāhā parṇebhyaḥ svāhā puṣpebhyaḥ svāhā ||* —*Taitt. S.*, VII, 3.19–20.

[b] *AV.*, VIII, 7.

[c] *AV.*, VIII, 12.27; Eng. trans. by Bloomfield.

Ṛgveda which clearly distinguishes wood (*dāru*) from the softer part of a tree. Majumdar (G. P.) (1) observes that the ancient Hindus differentiated the stem broadly into two parts—the outer called the *tvac*, *valkala* (skin) and the inner the *sāra*, that is the wood or essence enclosing the pith (*majjā*) and lasting till the end. The *Taittirīya Saṃhitā* separates the outer part into two layers, the outer *valka* and the inner *valkala*. The *Bṛhadāraṇyakopaniṣad*, while comparing a human being with a tree, provides some information about the internal structure of the latter as follows:

> 'A man is indeed like a mighty tree; his hairs are his leaves and his skin is its outer bark. The blood flows from the skin (of man), so does the sap from the skin (of the tree). Thus blood flows from a wounded man in the same manner as sap from a tree that is struck. His flesh (corresponds to what is) within the inner bark, his nerves are as tough as the inner fibres (of the tree). His bones lie behind his flesh as the wood lies behind the soft tissue (*śakara*). The marrow (of the human bone) resembles the pith (of the tree).'[a]

It is clearly noticed that a plant is divided internally into an epidermis (*tvac*), a bast or softer tissue (*śakara*), fibrous tissue (*kināṭa*) within the bast, the inner wood (*dāru*) and the pith (*majjā*) embedded in the wood.

From the use of such words as *śakṛt* (animal refuse) and *karīṣa* (dried cow-dung) in the *Ṛgveda* some scholars have inferred the knowledge of manuring, but such an interpretation does not readily follow from the context. The Ṛgvedic expression, *ā nimrucaḥ śakṛdeka apābharatkim* . . . , means 'one carries off the refuse at the sunset'. In the *Taittirīya Saṃhitā*, the cow-dung is hailed at one place, e.g. *yacchakṛt karoti tasmai svāhā*, but it does not imply knowledge of manuring. Somewhat indicative, however, is the following statement in the *Atharvaveda*:[b]

karīṣiṇīṃ phalavatīṃ svadhāmirāṃ ca no gṛhe |
audumbarasya tejasā dhātā puṣṭiṃ dadhātu me ||

which has been translated by Whitney as follows:

> 'Rich in manure, rich in fruit, *svadhā* and cheer in our house-prosperity let *dhātar* assign to me through the keenness of the (amulet of) *udumbara*.'

The *Taittirīya Saṃhitā* clearly mentions the ripening of corn twice in the year, *dviḥ samvatsarasya sasyam pacyate*,[c] but whether it also indicates

[a] *yathā vṛkṣo vanaspatiḥ tathaiva puruṣo'mṛṣā |*
lomāni parṇāni tvag asyotpāṭikā bahiḥ ||
tvac evāsya rudhiram prasyandi tvac utpaṭaḥ |
tasmād tadātṛṇṇāt praiti raso vṛkṣād ivāhatat ||
māṃsānyasya śakarāṇi kināṭam snāva tat sthiram |
asthīnyantarato dāruṇi majjā majjopamā kṛtā ||
—*Bṛh. Up.*, iii, 9.28.

[b] *AV.*, XIX, 31.3.

[c] *Taitt. S.*, V, I, 7.3.

rotation of crops, as stated by Majumdar,[a] is difficult to follow. Some idea as to the manufacture and storage of food may be obtained from stray references in the *Bṛhadāraṇyaka Upaniṣad*, and the *Maitrāyaṇī* and the *Kāṭhaka Saṃhitās*, where waters are regarded as the essence of the earth (*pṛthivyāḥ āpaḥ*), herbs as the essence of water (*apāmoṣadhyāḥ*), flowers as the essence of herbs (*oṣadhīnām puṣpāṇi*) and fruits as the essence of flowers (*puṣpānām phalāni*).[b]

From the time of the *Ṛgveda*, some conscious effort at classification is reflected in the naming of plants based on their morphological characteristics. Plants are in the first place broadly divided into three groups, e.g. trees (*vṛkṣa*), herbs (*oṣadhi*) and creepers (*vīrūdh*). Plants are also classified as flowering (*puṣpavatī*) and non-flowering, fruit-bearing (*phalavatī*) and fruitless.[c] All types of grass are described as *tṛṇa*. The *Atharvaveda*, as we have already noticed, subdivides the herbs into several types according to their morphological or other special properties, e.g. *prastṛnatī* (spreading), *stambinī* (bushy), *eka-śuṅgā* (with single calyx), *pratanvatī* (extending), *aṃśumatī* (rich in shoots), *kāṇḍinī* (jointed), *viśākhā* (having extending branches), *jīvalā* (lively), *naghāriṣā* (harmless) and *madhumatī* (richly sweet). Another interesting feature noticed in the *Vājasaneyī Saṃhitā*, *Tattirīya Brāhmaṇa* and the *Atharvaveda* is the description of an entire locality by the type of plants growing in that area, e.g. *naḍvala* (a place abounding in reeds), *śipālya* (a region where the plant *śipala* grows).

POST-VEDIC CLASSICAL PERIOD

Plant Science in Medical Works

For tracing the development of plant science in this period, we have again to depend largely on varied types of Sanskrit literature. In the first place, we have the medical treatises of Caraka, Suśruta, Vāgbhaṭa and their various recensions and commentaries, which carried on and further developed the Vedic emphasis on herbals for the treatment and cure of diseases and in the process recorded further progress made in the plant science in general. Caraka unhesitatingly observes that a pharmacologist is one who knows the uses and actions of herbs though he may not know their forms (morphology), but an expert physician is one who knows the herbs botanically, pharmacologically and in every other respect.[d] According to the *Dhanvantari Nighaṇṭu*, 'the physician does well to master *bheṣaja-vidyā* by acquainting himself with the various names of plants in Sanskrit and Prākṛt, consulting all classes of men, by personal observations, by a

[a] Majumdar (G. P.) (5), p. 103.
[b] *Bṛh. Up.*, vi, 4.1; *Mait. S.*, II, 4.8; *Kāṭh. S.*, XI, 10.
[c] *ṚV.*, X, 97.15.
[d] *yogvittvapyarūpajñastāsāṃ tattvaviducyate |*
kiṃ punaryo vijānīyādoṣadhīḥ sarvathā bhiṣak ||
—*CS. Sū.*, I, 122.

careful handling, as well as by a careful consideration of its specific characters and sexuality'.[a] The use of the term *bheṣajavidyā* is significant inasmuch as it implies the existence of a separate science devoted to the study of plants and plant-life with special reference to their medicinal properties.

Plant Science in the Purāṇas, Arthaśāstra and Bṛhatsaṃhitā

The *Agnipurāṇa*, the *Arthaśāstra* and the *Bṛhatsaṃhitā* have each a section or sections devoted to plant science (*vṛkṣāyurveda*) in general. These sections deal with collection and selection of seeds, germination, grafting, cutting, sowing, planting and nursing, soil selection, manuring, meteorological conditions favourable for plant growth, location of plants for improving the aesthetic and hygienic surroundings of the homestead, etc. All these sections, in which the agricultural bias is predominant, give one the impression that a separate *vṛkṣāyurveda* had been in existence concurrently with works on agriculture. Kauṭilya, in his chapter on the duties of the Superintendent of Agriculture, used the term *kṛṣitantra-gulma-vṛkṣāyurveda* and possibly indicated two departments of knowledge, one the *kṛṣitantra* dealing with agriculture and the other *gulmavṛkṣāyurveda* dealing with plant science. The existence of plant science as a separate branch of knowledge is also corroborated by Vātsyāyana's *Kāmasūtra* in which *vṛkṣāyurveda* is mentioned as one of the 64 arts recognized in ancient India. The existence of the *Kṛṣi Parāśara*, a well-known treatise on agriculture, has long since been known. The discovery of a manuscript of the *vṛkṣāyurveda*, also attributed to Parāśara, which we shall discuss in some detail further on, has now left no doubt as to the development of plant science as a separate branch of knowledge by its own right, possibly during the post-Vedic period, but before the beginning of the Christian era.

Philosophical and Miscellaneous Texts

The *Nyāya-Vaiśeṣika* texts and their commentaries, Amara's lexicography and the epics, the *Rāmāyaṇa* and the *Mahābhārata*, occasionally provide botanical information of value.

Parāśara's Vṛkṣāyurveda

In contrast to the type of literature mentioned above which is concerned with medicine, polity, epic poetry or matters of general interest and which deals with, or refers to, certain aspects of botany only incidentally, Parāśara's *Vṛkṣāyurveda* is a full-fledged treatise on plant science. A copy of the manuscript of this much referred to botanical work was discovered by the late Vaidyaśāstrī Jogendranath Viṣagratna of Navadwip, whose son N. N. Sircar published an account of it, with extensive quotations, in the *Journal of the Asiatic Society* in 1950. The work possibly dates from

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[a] Majumdar (G. P.) (1), pp. 8–9.

the first century B.C. or the first century A.D. Written in the *sūtra* style, the work is divided into six parts, e.g. *vījotpattikāṇḍa*, *vanaspatikāṇḍa*, *vānaspatyakāṇḍa*, *vīrūdhavallīkāṇḍa*, *gulma-kṣupakāṇḍa* and *cikitsitakāṇḍa*. The last part dealing with the treatment of plant diseases is missing from the extant manuscript. The first part, the *vījotpattikāṇḍa*, is further subdivided into eight chapters, e.g. *vījotpattisūtrīyādhyāya* (an outline of plant morphology), *bhūmivargādhyāya* (nature and properties of soil), *vanavargādhyāya* (description and distribution of forests), *vṛkṣāṅgasūtrīyādhyāya* (more detailed treatment of the morphology of plant members), *puṣpāṅgasūtrīyādhyāya* (flower, its parts, functions and classification), *phalāṅgasūtrīyādhyāya* (definition, function and classification of fruits), *aṣṭāṅgasūtrīyādhyāya* (discussion of eight plant limbs—root, stem, bark, heartwood, sap, excretions, oleaginous products and spines and prickles) and *dvigaṇīyādhyāya* (seeds and embryonic plants).

Sircar states that *Vṛkṣāyurveda* evidently formed the basis of botanical teaching preparatory to pharmaceutical studies in ancient India, an arrangement comparable to modern practice. It also appears that Parāśara's method of botanical nomenclature based on three types of synonyms, e.g. those of botanical significance (*paricayajñāpikā saṃjñā*), those with therapeutic index (*guṇaprakāśikā saṃjñā*) and those associated with names of habitats or special events, was largely followed by Caraka, Suśruta and other authors of medical treatises in preparing chapters on āyurvedic pharmacopoeias. Accordingly, a further importance attaches to this work inasmuch as it can help in the identification of plants mentioned in ancient medical treatises.

BOTANICAL KNOWLEDGE OF THE PERIOD

We shall now attempt to summarize the botanical knowledge as developed in this period and preserved in the various texts mentioned above, including Parāśara's special monograph on plant science. As before, it will be profitable to assess the materials under the conventional subject divisions such as seed and germination, morphology, physiology, ecology, taxonomy, and so on.

Seed and Germination

The technical term used for the seed is *vīja*. The seed is enclosed in a vessel called *vījakoṣa*. The kernel or endosperm is called *sasya* and the cotyledon *vījapatra*. Parāśara uses the term *vījamātṛkā* to denote cotyledon and recognizes monocotyledonous (*ekamātṛkavīja*) and dicotyledonous (*dvimātṛkavīja*) seeds. By this term is also meant the endosperm (*vījamātṛkā tu vījasasyam*), enclosing the *ādivījapatra* which may mean either the plumule or the cotyledon itself, which appears as the first leaf after germination. The cotyledon stores food material for the nourishment of the embryo.

Germination is expressed by the term *aṅkurodbheda*, which means sprouting of the seed to life; *aṅkura* means the seedling. Conditions for successful germination are given as air, water and the season guaranteeing the proper warmth. According to Suśruta, proper season, good soil, requisite supply of water and good seeds all taken together help in the germination of seed.[a] Guṇaratna in his commentary on the *Ṣaḍdarśana-samuccaya* states that the seeds of *vaṭa* (*Ficus indica*), *pippala* (*Ficus religiosa*), *nimba* (*Melia azadirachta*) and others germinate during the rainy season under the influence of dew and air.[b]

Parāśara gives a more graphic description of the process of germination. During the sprouting up of the seedling (*praroha*), its body receives nourishment from the cotyledons. This nourishment enables the seedling to grow until its root develops and comes of its own. The cotyledons dry up as soon as the seedling is able independently to receive nourishment directly from the soil of the earth.[c]

MORPHOLOGY

Root

Plants are divided broadly into two parts, the subterranean part called *mūla* (root) and the aerial part called *vistāra* or *tūla* (shoot). The *mūla* means an organ by which the plant is fixed to the soil. The use of the word *pādapa* to mean a plant is significant as it implies the ability of the plant to absorb water from the soil with the help of its root, the *pāda*. Various types of adventitious root—fibrous roots originating in the branches (*śākhā śiphā*), prop roots (*avaroha*)—are recognized. The *Arthaśāstra* indicates knowledge of edible bulbous roots.

Shoot and Stem

The shoot comprises the stem and leaves. The stem is called *kāṇḍa* and the main stem, that is the portion between the root and the place of origin of the branches, *prakāṇḍa*. The Vedic term *skandha* is also retained. In the case of *vanaspati* and *vānaspatya*, stems are strong and erect, whereas in the case of *vallī*, *vratatī* or *latā*, these are weak, necessitating some kind of support such as trees which these may embrace or entwine (*vallī veṣṭayate vṛkṣam*). Plants may be with or without stems. Nodes (*parva* or *granthi*) and internodes, caudex (*sthānu*) and branches in the descending order—*śākhā*, *pratiśākhā* and *anuśākhā*—are described. Underground stems which

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[a] *ṛtu kṣetrāmbubijānāṃ sāmagryādaṅkuro yathā* |
—*SS. Śā.*, ii, 33.

[b] *vaṭapippalanimbādīnāṃ prāvṛḍjaladharaninādaśiśiravāyu saṃsparśādaṅkurodbhedaḥ* |
—*Ṣd. S.*, p. 157.

[c] *aṅkuranirvṛtte bījamātṛkāyā rasaḥ saṃplavate prarohāṅgeṣu* | *tenaiva rasena prarohaḥ snihyate vardhate ca yāvanmūlaṃ na svatantravṛttiḥ syāt* | *yadā prarohaḥ svātantrena bhūmyāḥ pārthivarasaṃ gṛhṇāti tadā bījamātṛkā praśoṣamāpadyate* ||

act like roots but are not true roots are recognized and termed *kanda* (*yan-mūlameva vījaṃ sa kandaḥ*).

Differentiation of plants into trees, shrubs and herbs on the basis of their stems being long or short, hard or less strong, or succulent is noticeable. The term *vṛkṣādanī* meaning a guest plant sucking food from the host plant clearly points to a parasite, and the term *vṛkṣārūhā* (living on another tree) is nothing but the description of epiphytes. Mosses (*śaivāla*), green algae (*jalanīlī*) and mushroom (*chatrā*) are recognized as lower plants.

Leaf

Patra and *parṇa* used to denote leaf are derived from its falling nature and its green colour. A leaf may be petiolate (*savṛnta*, *patravṛnta*) or sessile (*vṛntahīna*). The leaf blade or lamina is called *pakṣa* and may be, according to Parāśara, of four kinds, e.g. *samapakṣa* (two wings symmetrical), *viṣamapakṣa* (two wings asymmetrical), *samakarṇa* (symmetrically incised) and *viṣamakarṇa* (asymmetrically incised). In the petiolate leaf, the petiole may be attached to the base of the lamina (*prāntagranthika*) or to the axis (stem) (*vṛntabandhana*). The *Vṛkṣāyurveda* reveals knowledge of the phyllotaxis called *patrabandhana*, of which various types are dealt with. Compound leaves are differentiated from the simple and named after the number of leaflets, e.g. *dvipatra*, *tripatra*, *saptapatra*, and so on. The leaves have also been described and named after their shapes, e.g. *aśvaparṇaka* (*Shorea robusta*), resembling the ear of a horse, *muṣikaparṇī* (*Salvinia*), resembling the ear of a mouse, *kīśaparṇī* (*Achyranthes aspera*), resembling the ear of a monkey.[a]

We now know that there are two principal types of venation, e.g. parallel in which the veins run more or less parallel to one another, and reticulate when the veinlets are irregularly arranged. Parāśara observes that veins carry nutrients to the leaves and are visible like so many lines. The venation is of two types, namely *praguṇa* and *vellita*; in the former the veins are arranged in parallel and in the latter obliquely in the form of a network. Leaves characterized by *praguṇa* venation are called *mauñjapatra* and those by the *vellita* are termed *jālikapatra*.[b]

Flower

Parts of a typical flower are named as *prasavabandhana*, *puṣpavṛnta* (pedicel), *sthālaka* (thalamus), *jālaka* (sepals), *dala*, *puṣpadala* (petals). No suitable name for androecium is available, but its component parts, e.g. stamens (*keśara*), anther (*kiñjalka*) and pollen grains (*parāga*, *keśarareṇu*), are recognized. Likewise, the parts of a gynoecium are named as *vījādhāra* (ovary), *varāṭaka* (style) and *varāṭakaśīrṣa* (stigma).

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[a] Majumdar (G. P.) (1), pp. 23–24.

[b] *patrasirā tu patre rekhāṅkitena dṛṣṭavatī rasavahā ca | patre sirānāṃ sanniveśaṃ dvividhaṃ bhavati | praguṇaṃ vellitañca | tatra praguṇamṛjukrameṇa yatsaṃsthānam | . . . praguṇena mauñjapatraṃ vellitena tu jālikapatraṃ saṃjñāyate |*

In the chapter entitled *puṣpāṅgasūtrīyādhyāya* of the *Vṛkṣāyurveda*, the peculiarities in the arrangement of floral leaves, particularly the gynoecium in the thalamus, have been used as criteria for classifying flowers into four types, e.g. *tundapuṣpamaṇḍala, kumbhapuṣpamaṇḍala, tuṅgapuṣpamaṇḍala* and *vāṭyapuṣpamaṇḍala*. The first is a typical flower and is hypogynous (*puṣpakrānta-vījādhāra*); that is stamens, petals and sepals are inserted below the gynoecium. In the second type, sepals, petals and stamens are inserted above the gynoecium, that is flowers belonging to this type are epigynous (*puṣpaśīrṣa-vījādhāra*). In the *tuṅgapuṣpamaṇḍala*, the thalamus assumes the form of a cup and supports the gynoecium in the middle and the stamens, petals and sepals along the rim, giving rise to perigynous (*sthalakotsaṅga*) flowers. In the fourth type, the stamens are fused to form a tube or an elongated mortar (*ulukhala*) covering up the ovary. Flowers of this class described by Parāśara as *vāṭyamaṇḍalagaṇa* are typical of the Malvaceae family.

Fruit

Different kinds of fruits such as green (*śalātu*), fleshy (*kṣīraka*), dry (*vāna*) and legume (*śamī, śimba*) are recognized. Parāśara has a special chapter on fruits (*phalāṅgasūtrīyādhyāya*), in which functions and classification of fruits are discussed.

HISTOLOGY

Development of preliminary ideas as to the internal structure of plants has been noticed in the Vedic literature, particularly in the *Upaniṣads*. The *Vṛkṣāyurveda* records considerable advancement in this field by presenting a detailed internal structure of the leaf. This was thought necessary to explain the function of the leaf about which Parāśara had a few interesting observations to make. A leaf contains a large number of invisible (*aṇavaśva*) cells (*rasakoṣa*), each covered by a cell-wall (*kalāveṣṭitena*) of fine membrane (*sūkṣmapatrakā*). These cells store the sap containing the five elemental properties (*pāñcabhautikaguṇa samanvitasya rasasyāśayaḥ*) as also a colorific principle (*rañjakayukta*). The plant body possesses several transporting systems (*sarvasrotāṃsi*). This system in the stem, which distributes *rasa* from the earth to the various plant organs, is called *syandanī*, and the one working in the leaves is called *sirājālāni*. The transporting system has both upward and downward channels (*sirābhiścopasarpayanti apasarpayanti ca bhāvābhāvau*).

PHYSIOLOGY

That plants possess several characteristics of life such as growth, movement, sleep, waking, disease, transmission of characters, etc., was noticed by the various philosophical schools in India. Udayana of the *Vaiśeṣika*

school observes, in his *Kiraṇāvalī*, that plants constantly manifest the phenomena of living, death, dream, waking, susceptibility to diseases, drugging, movement towards what is favourable and repulsion from what is unfavourable as if these are living bodies.[a] The Buddhist logician Dharmottara records, in his *Nyāyavinduṭīkā*, the phenomenon of sleep in certain plants, in the form of contraction of their leaves during night. Guṇaratna, in his *Ṣaḍdarśana-samuccaya*, enumerates different characteristics of life. The plants pass through three stages of infancy, youth and age; they have growth; their various kinds of movement are conditioned by sleep, waking, response to touch or need for support. Plants are able to deal with wounds and laceration sustained by their organs and make use of drugs to overcome wounds as well as diseases. Assimilation of the food from the soil is determined by requirements of plants for growth, decay, fighting for diseases, and so on.[b] A list of plants showing the phenomena of sleep and waking is mentioned, and *lajjāvatī latā* (*Mimosa pudica*) is specifically cited as an instance of a plant sensitive to touch. The different philosophical schools in India had thus unanimously recognized plants as living organisms. That such a view must have crystallized during the period of the *Saṃhitās* and *Upaniṣads* is borne out by frequent comparison of plants with animals as, for example, the likening of the plant to the human body to which we have already referred.

Nourishment

As to the physiology of nourishment, scattered references amply indicate the knowledge that plants receive their food materials from the soil in the form of solution through the agency of the root. The use of the term *pādapa* for the root, as already pointed out, is significant. In the *Mahābhārata*, plants are stated to drink water with the help of air just as water is sucked to the mouth through the lotus petiole.[c] Majumdar has argued that the analogy, though imperfect, indicates that 'the knowledge of the existence of the sucking force in the leaves of trees corresponding to the existence of a sucking force in the mouth of man—a knowledge which is only a very recent discovery—was an accomplished possession with the ancients'.[d] Parāśara's transporting systems, e.g. *syandanī* in the stem and *sirājālāni* in the leaves, are clearly stated to be engaged in the important work of transporting and circulating sap. The phenomenon of the circulation of sap also appears in Kaṇāda's *Vaiśeṣika Sūtra*: *utsrotasastamaḥ*

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[a] *vṛkṣādayaḥ pratiniyatabhoktradhiṣṭhitāḥ jīvanamaraṇasvapnajāgaraṇarogabheṣajaprayogasajātīyānuvidhyānukūlopagamapratikūlāpagamādibhyaḥ | prasiddhaśarīravat |*
—*Pṛthivīnirūpaṇam*

[b] Seal, pp. 173–74.

[c] *vaktreṇotpalanālena yathordhvaṃ jalamādadet |*
tathā pavanasaṃyuktaḥ pādaiḥ pivati pādapaḥ ||
—*Śāntiparva*, 177.16.

[d] Majumdar (G. P.) (1), p. 32.

prāyā antasparśā viśeṣinaḥ.[a] Moreover, Parāśara's elaborate histology of the leaf and recognition of the presence in it of colouring matters (*rañjaka*) are not without significance, as these together with the use of such expression as *rañjakena pacyamānāt* (digested with the help of colouring matters), according to Sircar, point to the knowledge of food manufacture in the leaves.

Plant Pathology

Plant diseases and their treatment received careful attention. According to Varāhamihira, plant diseases are caused by cold climate (low temperature), wind (dryness) and sun (heat) and indicated by the yellowness of the leaves, non- or under-development of buds, dryness of the branches and the exudation of the sap. The same view is held by Kāśyapa. Guṇaratna observes that plants are afflicted by diseases, displacement or dislocation of flower, fruit, leaves and bark in the same way as the human body suffers from jaundice, dropsy, emaciation, stunted growth of finger, nose, etc., and respond to treatment like human bodies. Varāhamihira's prophylactic treatment includes the application to the root of mud kneaded with ghee and *viḍaṅga* and thereafter of milk diluted with water. The *Agnipurāṇa* prescribes a mixture of *viḍaṅga* with rice, fish and flesh. For the cure of barrenness, the *Bṛhatsaṃhitā* and the *Agnipurāṇa* prescribe a hot decoction prepared of *kulattha* (*Dolichos biflorus*), *māṣa* (*Phaseolus mungo*), *mudga* (*Ph. radiatus*), *tila* (*Sesamum indicum*) and *yava* (barley), which is to be applied to the root.

Reproduction, Sex and Heredity

Reproduction of plants by fruits and seeds, roots, cuttings, graftings, plant apices and leaves was well known.[b] Buddha Ghoṣa, in his *Sumaṅgala-vilāsinī*, a commentary on the *Dīgha Nikāya*, describes some of these methods under such terms as *mūla-vīja* (root-seed), *khaṇḍabīja* (cutting), *phaluvīja* (joints), *agravīja* (budding) and *bīja-bīja* (seed). Propagation by seeds (*bīja-bīja* or *vījarūha*) is referred to in the *Atharvaveda* and by Manu. The *Arthaśāstra* mentions cases of plant propagation by bulbous roots (*kāṇḍavīja*). The method of cuttings (also called *skandhavīja*) is described in the *Arthaśāstra*, *Bṛhatsaṃhitā* and *Sumaṅgala-vilāsinī* in the case of sugar-cane, jack-fruit, blackberry, pomegranate, vine, lemon tree, *aśvattha* (*Ficus religiosa*), *nyagrodha* (*Ficus bengalensis*), *udumbara* (*F. glomerata*) and several others. The method of grafting which consists in inserting the cutting of one tree into the stem of another is considered by Varāhamihira as superior to cutting. Plants like betel, *samiraṇa*, *ajjuka* (*Ocimum basilicum*) and *hiriverum* (*Andropogon cynanthus*) are propagated by the *agravīja* method.

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[a] *VS.*, 5.2.7.

[b] Majumdar (G. P.) (1), pp. 62–65.

Some vague ideas regarding sexuality in plants are noticeable in the *Hārita-* and *Caraka-saṃhitās.* Questions are raised as to why there are no flowers and fruits produced except sexually or why the same kind of fruition is not perceived in women as in plants. One answer, put in the mouth of Ātreya, is that the seed is the result of co-operation of different sexes among the creeping and the fixed plants, and its quality varies according to the sperm.[a] The fixed plants are endowed with the male (*śiva*) and the female (*śakti*) principles. Caraka recognizes male categories of plants bearing white flowers, large fruits and tender leaves and the female categories characterized by yellow flowers, small fruits, short stalk, etc. Of special importance is the case of *ketakī* (*Pandanus odoratissimus*) mentioned in the *Rājanighaṇṭu* and the *Dhanvantari Nighaṇṭu.* Always referred to as a couple (*ketakīdvaya*), the male plant is called the *sītaketakī* and the female one the *svarṇaketakī.* The former is sometimes called simply *ketaka* in the male gender or *biphalā*, that is unproductive of fruits, and the latter *kanakaprasavā*, that is the plant which produces a golden harvest.

From the time of the *Brāhmaṇas*, the question of transmission of characters has been posed. Caraka and Suśruta go as far as to state that the fertilized ovum contains in miniature all the organs of the plant, e.g. the bamboo seed containing in miniature the entire structure of the bamboo tree, and further that the male sperm cells have minute elements derived from each of its organs and tissues. Such ideas closely resemble Darwin's 'gemmules' and Spencer's 'ids'.

TAXONOMY

Systematization of any branch of knowledge through proper nomenclature and classification appears to be a speciality of the ancient Indians. This is clearly noticeable in botany which provides a natural scope to the systematizer.

Nomenclature

Plants have been named in consideration of (1) special association, (2) special property such as medicinal, domestically useful, etc., (3) morphological characteristics, e.g. shape of leaf, number of leaflets in a compound leaf, shape and colour of flowers, etc., (4) local association, (5) environmental association and (6) other peculiarities. An attempt to express either the salient external features or some prominent qualities, medicinal or otherwise, is clearly reflected in the system. Thus *bodhidruma* (*Ficus religiosa*), *aśoka* (*Saraca indica*) and *śivaśekhara* (Datura) are examples of special association; *dadrughna* (*Cassia fistula*), *arśoghna* (*Amorphophallus campanulatus*), *kuṣṭhanāśinī* (*somaraji*), *dantadhāvana* (*Acacia catechu*), *kārpāsa*

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[a] *viruddhānāñca vallīnaṃ sthāvarāṇāñca putraka |*
tatra dhātusamaṃ vījaṃ sahayogena varttate || —*HS. Śā.*, **1**, 12–14.

(cotton) and *lekhana* (reed) utilize medicinal and domestic properties; *kīśaparṇī* (*Achyranthes* sp.), *aśvaparṇaka* (*Shorea robusta*), *pañcāṅgula* (*Ricinus*), *tripatra*, *saptaparṇa*, *vakrapuṣpa* (*Sesbania grandiflora*) and *śatamūlī* (asparagus) depend upon morphological peculiarities of leaf, flower, root, etc.; *saubīra* (*Zizyphus jujuba*), *māgadhī* (jasmine), *vaidehī* (pepper), *jalaja*, *paṅkerūha* (lotus) and *maruvaka* (*Ocimum* sp.) are examples of naming on the basis of local or environmental associations. Consideration of so many factors has often led to the coining of multiple names for the same plant, e.g. *vakrapuṣpa* (plant having curved flowers) and *vraṇārī* (enemy of boils) for the plant *Sesbania grandiflora*; *kaṇṭaphala* (having spiny fruits), *ghaṇṭāpuṣpa* (possessing bell-shaped flowers) and *mahāmohī* (great intoxicator) for the plant *Datura alba*.[a] The system impressed William Jones so much that he remarked that Linnaeus would have probably adopted the Hindu method had he known the Sanskrit language.

Classification

Plants were classified in accordance with three distinct principles, e.g. botanical (*udbhida*), medicinal (*virecanādi*) and dietetic (*annapānādi*). Compared to the broad Vedic classification of plants into *vṛkṣa*, *oṣadhi* and *vīrūdh*, attempts of this period are much more elaborate and scientific.

Manu divided plants under eight classes as follows:[b]

(1) *Oṣadhi*—bearing abundant flowers and fruits, but withering away after fructification, e.g. rice, wheat.
(2) *Vanaspati*—bearing fruits without evident flowers.
(3) *Vṛkṣa*—bearing both flowers and fruits.
(4) *Guccha*—bushy herbs, e.g. *Jasminum* (*mallikā*).
(5) *Gulma*—succulent shrubs.
(6) *Tṛṇa*—grasses.
(7) *Pratana*—creepers which spread their stems on the ground.
(8) *Vallī*—climbers and entwiners.

Suśruta and Caraka more or less adhered to the broad-based classification of the Vedic period and recognized some of the classes given by Manu as forming subclasses. According to them, plants are of four classes:[c]

(1) *Vanaspati*—which bears fruits but not flowers.
(2) *Vṛkṣa* or *vānaspatya*—which bears both fruits and flowers.
(3) *Vīrūdh*—which creeps on the ground or entwines.
(4) *Oṣadhi*—annual herbs which wither away after fructification.

Suśruta's commentator Ḍalhaṇa gives *plakṣa* (*Ficus infectoria*) and *udambara* (*Ficus glomerata*) as examples of *vanaspati* and the mango and

[a] Majumdar (G. P.) (1), pp. 71–78.
[b] *MS.*, I, 46.47.48.
[c] *tāsāṃ sthāvarāścaturvidhāḥ | vanaspatayo vṛkṣā vīrūdh oṣadhaya iti | tāsu apuṣpāḥ phalavanto vanaspatayaḥ puṣpaphalavanto vṛkṣāḥ | pratānavatyaḥ stambinyaśca vīrūdhaḥ, phalapākaniṣṭhā oṣadhaya iti* || —*SS. Sū.*, 1.23

the *jambu* (*Eugenia jambolana*) as examples of fruit- and flower-bearing *vṛkṣas*; subdivides *vīrūdhs* into two groups, *pratānavatya* (creepers with spreading stems on the ground) and *gulminya* (succulent herbs); and cites wheat and barley as examples of *oṣadhi* which wither away after fructification. Caraka's commentator Cakrapāṇi subdivides *vīrūdhs* into *latā* (creeper), *gulma* and *oṣadhis* into annuals or perennials bearing fruits and grasses which go without fruits.

The *Vaiśeṣikas* classify plants under seven heads, e.g. *vṛkṣa*, *tṛṇa*, *oṣadhi*, *gulma*, *latā*, *avatāna* and *vanaspati*.[a] Defining the characteristics of the various groups, Udayana, in his *Kiraṇāvalī*, remarks that *vṛkṣas* are plants endowed with trunks and branches bearing flowers and fruits (*vṛkṣāḥ puṣpaphalavantaḥ skandhaśākhinaḥ*); *tṛṇas* are exemplified by *ulapa* and like plants (*tṛṇānyulapādīni*); *oṣadhis* are plants like *kalama*, which perish after their fruits ripen (*oṣadhyaḥ phalapākāntāḥ kalamādayaḥ*); *gulmas* are plants like *bhāṭā* (*gulmā bhāṭāḥ*); *latās* are represented by *kuṣmāṇḍa*, a species of *Cucurbita* (*latāḥ kuṣmāṇḍīprabhṛtayaḥ*); *avatānas* are plants like *ketakī* (*avatānāḥ ketakyādayaḥ*); and *vanaspatis* are trees that produce fruits without flowers (*vanaspatayo vinā puṣpaṃ phalinaḥ*).

Parāśara, in his *Vṛkṣāyurveda*, has developed a more elaborate classification based largely on morphological consideration such as floral characters, their resemblances and differences. In his system, plants are classified into families (*gaṇa vibhāga*), of which some examples are given below:

Samīgaṇīya (*Leguminosea*)—This family is represented by *samī-vṛkṣa*, a plant bearing *simbiphala*, i.e. a legume or pod, and leaves held on a common stalk, which are compound in nature, with leaflets arranged like a feather. Flowers of plants of this family are hypogynous (*puṣpa-krāntabījādhāra*) and five-petalled, with gamosepalous calyx and an androecium of 10 stamens. Three subtypes are: *vakra-puṣpa*, *vikarṇika-puṣpa* and *śuka-puṣpa*.

Puplikagaṇīya (*Rutaceae*)—The plants bear spines, odoriferous leaves and winged petioles and hypogynous flowers (*tundamaṇḍala*) with free petals and stamens. Fruits formed of superior ovary (*puṣpa-krāntaphala*) contain hairy succulent flesh and multiple seeds. *Keśa-raka* and *māluraphala* are its two subtypes.

Svastikāgaṇīya (*Cruciferae*)—The name is derived from the shape of the calyx which looks like a *svastikā*. The flower has four sepals, four petals and six stamens, all free, and a superior ovary (*tunda-maṇḍala*). In the inflorescence flowers are arranged in rows. The two carpels are fused to form a bi-locular fruit (*dvipuṭa*) of which the wall is sutured to give it the appearance of a leguminous fruit.

Tripuṣpagaṇīya (*Cucurbitaceae*)—Plants of this class bear epigynous (*kumbhamaṇḍala*) flowers which are sometimes unisexual. The flower has five sepals, five petals which are united, three stamens and a style

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[a] *sthāvarāḥ vṛkṣatṛṇauṣadhigulmalatāvatānavanaspataya iti* ||
PBh. Dravya, pṛthivīnirūpaṇam.

with three-pointed stigma (*triśīrṣavarāṭa*). The ovary is tri-locular (*trivartaka*) and produces several seeds.

Mallikāgaṇīya (*Apocynaceae*)—Plants of this class give an inflorescence of a mixed type and bear hermaphrodite (*samāṅgā*) flowers having united calyx and corolla, each five-membered, and five stamens, epipetalous (*avyaktakeśara*). The fruit is a follicle of two chambers and seeds are endowed with tufts of long fine hairs (*tulapucchasamanvitā*).

Kurcapuṣpagaṇīya (*Compositeae*)—In this case, the flowers are sessile and borne on a common axis surrounded by a common calyx so as to make the assemblage look like bristles on a brush head (*kurcākāra*), whence the name. The ovary is inferior (*puṣpaśīrṣakabījādhāra*).

ECOLOGY

The period under review shows some awareness of the dependence of structural and functional peculiarities of plants upon environmental conditions. Caraka and Suśruta divide land into different regions according to the nature of soil, climate and vegetation. There are several references to plants typical of these regions, which clearly indicate their interest in plant ecology. The regions and their characteristic vegetation may be summarized as follows:

Jāṅgala region is characterized by open spaces, dry wilderness or deserts, and scarcity of rivers and rivulets, in fact, of water resources in general. Some of the typical plants of this region, as mentioned by Caraka, include *khadira* (*Acacia catechu*), *śallakī* (*Boswellia serrata*), *sāla* (*Shorea robusta*), *aśvattha* (*Ficus religiosa*), *vaṭa* (*F. bengalensis*), *āmalakī* (*Phyllanthus emblica*) and *śiṃśapā* (*Dalbergia sissoo*).[a]

Anūpa region means a marshy or swampy tract, abounding in a large number of pools, traversed by a net of rivers and overgrown with forests. The vegetation of *anūpa* region, according to Varāhamihira, includes *jambu* (*Eugenia jambolana*), *vetasa* (*Calamus rotung*), *kadamba* (*Anthocephalus cadamba*), *drākṣā* (vines), *arjuna* (*Terminalia arjuna*) and several others. According to Caraka, dense forests of *hintāla* (*Phoenix paludosa*), *tāla* (*Borassus flabellifer*), *tamāla* (*Cinnamomum tamala*) and *nārikela* (*Cocos nucifera*) typify such swampy regions.

Sādhāraṇa, meaning ordinary, is an intermediate region which has some features common to both the *jāṅgala* and the *anūpa*. Such regions are good for the growth of both *vanaspatis* and *vānaspatyas*.

Kauṭilya differentiated between the *jāṅgala* and the *anūpa* regions by the amount of rainfall. For the *jāṅgala*, this amount is 16 *droṇas*, whereas for the *anūpa* it is half as much more.[b]

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[a] Majumdar (G. P.) (1), p. 67.
[b] *AŚ.*, II, 24.

ARBORI-HORTICULTURE

The science of arbori-horticulture developed during this period as a distinct discipline. Much of the *Vṛkṣāyurveda* deal with the construction and maintenance of gardens and parks for health, recreation and enjoyment of the public. The existence of the science in a rudimentary form can be traced to the Ṛgvedic times. All decent houses and places of noblemen and kings had pleasure and kitchen gardens attached to them.

Public gardens and parks were placed under the charge of superintendents who were required to know the causes of growth and development of flowers and fruits, the methods of planting and curing trees by the administration of proper soil and water at the suitable time and the various uses of plants as medicinal drugs. The knowledge of grafting was one of the qualifications of the gardener, and it came to be regarded as one of the 64 *kalās* or arts. According to Vātsyāyana, all big houses and palaces of kings had a pleasure garden, *vṛkṣavāṭikā* or *puṣpavāṭikā*.[a] Methods of plant propagation by seed, cutting, layering, grafting and budding were prevalent and one finds mention of them in the *Vedas*, *Arthaśāstra* and *Bṛhatsaṃhitā*. Jacolliot remarked, 'We should not forget that India, that immense and luminous centre in olden times, was in constant communication with all the people of Asia and that all the philosophers and sages of antiquity went there to study the science of life.'[b]

In the Buddhist literature we find description of pleasure gardens of king Bimbisāra and Aśoka as places of diversion. The tree at Buddha Gaya under which Gautama attained enlightenment was a *pipul* (*Ficus religiosa*) and its branches were taken far and wide and planted.

We have a chapter entitled the *Upavanavinoda* as a branch of *Vṛkṣāyurveda* in Śārṅgdhara's encyclopedic work, the *Śārṅgdhara Paddhati*, composed during the thirteenth century A.D. The text has been edited and translated by Majumdar (G. P.) (3). The treatise was compiled at the command of his king for the benefit of his subjects. The following topics are discussed: glory of trees; good and evil omens relating to residence near the trees; selection of soil; classification of plants; sowing of seeds; watering of plant; the rule for the protection of plants; construction of garden houses; examination of soil where wells are to be dug; rules for nourishment of plants; *kunapa* water (recipe for natural solution); treatment of plants in diseases and health; and botanical marvels (experimental results).[c] The *Arthaśāstra*, the *Kāmasūtra*, the *Śukranīti* and literature of this class indicate that there were forest departments which were placed under expert forest officers whose duty it was to develop new plantations, administer forest laws and accomplish in every possible way the economic development of the forest resources of the State.

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[a] Majumdar (G. P.) (5), p. 27.

[b] Maheshwari, Sen Gupta aud Venkatesh, p. 165.

[c] For a brief summary, *see* Majumdar (G. P.) (5), p. 29.

In Vālmīki's *Rāmāyaṇa*, the poet lists several plants of the Chitrakuṭa Hills while describing the journey of Rāma, Lakṣmaṇa and Sītā. Mention is made in the *Rāmāyaṇa* that Sītā was confined by Rāvaṇa in a grove of Aśoka trees (*Saraca indica*). *Kadamba* (*Anthocephalus cadamba*) was closely connected with the life of Śrīkṛṣṇa, and its abundance in the past near Mathurā and Brindāban is perhaps an evidence of more humid climate prevailing in this area in those days.

Tulasi (*Ocimum sanctum*) had the pride of place and is still grown in many Hindu houses.

Lotus (*Nelumbo nucifera*) is referred to in the *Purāṇas*. Brahmā emerged from the lotus which grew out of the navel of Viṣṇu. In the days of Mohenjo-daro, lotus blossoms were wreathed over the head of the Sun-god. Sidhu was prepared from the flowers of *mahuā* (*Madhuca indica*) tree, *kharjura* from juice of date-palm (*Phoenix sylvestris*) and *surā* from cereals. Cannabis fibre (*Cannabis sativa*) was known and *bhāṅg* prepared from its leaves was often used as an intoxicant. Among the beverages, fermented drinks were known, as there was *somarasa*, the drink of the gods. In spite of its special virtue of giving immortality, the origin of *somarasa* remains unsolved. *Rauwolfia serpentina*, which has now earned world-wide popularity, finds mention in ancient Hindu manuscripts as well as in *Caraka*. The plant is described, under its Sanskrit name *sarpagandhā*, as a useful remedy for snake-bite and insect-stings. Because of its curative effect in cases of insanity it has long been known in Hindi as *Pagal-ki-Dawa*.

Kālidāsa refers to plants featured in personal adornment and beautification at the home, e.g. *tāmbūla* or pān (*Piper betle*), *supāri* (*Areca catechu*), cardamom (*Elettaria cardamomum*), *ćampaka* (*Michelia champaca*), sandal paste (*Santalum album*), etc. The *Bṛhatsaṃhitā* contains references to various types of toothpicks, hair-oils, perfumes and recipes for dyeing the hair.

Bengal had direct maritime intercourse with the Far Eastern countries. China and the Far East used to import at least a part of the sandalwood (*Santalum album*) from India even up to about the eighth or ninth century A.D. Sandalwood was a 'royal tree' and people had no right to its cultivation. It was a naturally growing plant in India. The appearance of sandal trees along with mango (*Mangifera indica*) trees in the sculptured railings of Bhārhut is a proof of their growing in India at least from the second century B.C.

Of the greatest importance as an article of export, was black pepper (*Piper nigrum*), a native of the western coast of India. It was well known to the Greeks and later taken to Europe by Arab traders either through the Persian Gulf, Mesopotamia, Syria or through the Red Sea and the Gulf of Suez. At one time pepper was weighed against silver and gold and it was the high price of pepper which acted as the chief incentive for Europeans to find a sea route to India.

BOTANY IN THE MEDIEVAL PERIOD FROM ARABIC AND PERSIAN SOURCES

K. A. CHOWDHURY

To start with, written information for this period on botany, as a biological science, is almost nil. Nobody seems to have taken enough interest to collect basic knowledge in various disciplines of botany, such as classification, morphology, physiology and ecology, etc. The main emphasis has been on the utilization of plant products for food, shelter and clothes. Almost all the reports are confined to agriculture, horticulture and forest produce. From this scanty information it is not possible to trace chronologically the advancement of knowledge in any of these products. Some broad-based general conclusion is, however, possible and that is what has been done here.

Speaking generally, the agricultural produce of the country as a whole could not have been very much different from what it is today. A few plants introduced in the country during this period will be dealt with elsewhere.

Wheat

During the reign of Delhi Sultanate, according to Amir Khusrau,[a] the chief crops were pulses, wheat, barley, millet, peas, rice, sesame oilseeds, sugar-cane and cotton. Canal irrigation introduced by Fīrūz Shāh Tughluq near Hissar and Fīrūzābād greatly improved the production of wheat, sugar-cane, sesame and pulses in these areas. The city of Delhi used to get wheat, rice and sugar-cane from Manikpur (near Allahabad) because of the high quality of crops produced there. During Akbar's time wheat (*Triticum* sp.) was grown throughout north India, and in the states of central, western and eastern parts. In Bengal wheat was grown in sufficient quantity although it was recognized that the quality was not so good.[b] During this period of 600 years, no mention has been made of varieties of wheat in any record. This is rather surprising because with different climate-soils, complex in the country with almost no irrigation, one could expect varieties of wheat which would grow well in different localities.

Rice

Cultivation of rice (*Oryza sativa* L.) during Akbar's time shows that more than one variety was in existence. According to *Āīn*,[c] three varieties were cultivated in the subahs of Agra, Allahabad and Oudh. These were dark-coloured rice (Persian: *shali mushkin*), *munj* rice (believed to be related to the present *bāsmatī* variety grown in Dehra Dun and adjoining

[a] Ashraf, p. 20.
[b] Habib, p. 37.
[c] Sarkar (J.), II, pp. 181–90.

districts) and the common rice. Another variety that used to be grown in Bengal is mentioned also in the *Āin* as given below:[a]

> 'If single grains of each kind were collected, they would fill a large vase. It is sown and reaped three times in a year, on the same piece of land with little injury to the crop. As fast as the water rises, the stalks grow, so that the ear is never immersed; inasmuch as those experienced in such matters have taken the measure of a single night's growth as six cubits.'

There may be a slight exaggeration here but we know that this variety of rice is still grown in certain parts of Assam and Bengal.

Another point to note here is that agriculturists by using selection method had classified rice into varieties and utilized the different varieties to suit different environmental conditions. In view of the past history of rice cultivation in India, one wonders whether the experience of rice cultivation for such a long time is not responsible for an advanced knowledge in this cereal.

Barley

Jgu (*jav*) (*Hordeum vulgare* L.) was usually cultivated where wheat was grown. There was no barley cultivation in Bengal and Assam. Generally speaking, the proportion of wheat and barley cultivation was 3:1. According to *Āin*, about 1/5 of the entire land under cultivation was covered by barley.

Millets

Under the general term millet, many small-grained cereals are cultivated, mostly in the drier parts of the country. During Akbar's time tax was imposed on the following millets:

Persian names	*Hindusthani names*	*English names*	*Latin names*
Jowar	Sorghum, joar	Great millet	*Sorghum vulgare* Pers.
Shamakh	Sanwan, sanwa	Japanese millet	*Echinochloa frumentacea* (Roxb.) Link.
Kodron	Kodu, kondo?	Kodo millet	*Paspalaum scrobiculatum* L.
Gal or kunguni	Kangri, kangu kukum	Italian or horse-tail millet	*Setaria italica* L. Beau
Arzan	Chin, morhi, anu	Common millet	*Panicum miliaceum* L.
Manwah	Mandua, mandal	Ragi finger millet	*Eleusine coracana* (L.) Gaertn.
Lahdarah	Bajra	Bulrush or pearl millet	*Pennisetum typhoides* (Burm. f.) Stapf and C. E. Hubb.
Kudiri	?	?	?
Barti	?	?	?

[a] Sarkar (J.), II, p. 134.

Of these, almost all are cultivated at the present time.[a] A point to note here is that these small cereals were cultivated in those days because either they were eaten by the poorer sections of people or they were used as fodder. It is most likely that the latter was the case, because it is repeatedly mentioned that pasture covered extensive area of the land. For instance in Bengal, where there are now few pasture lands, an extensive area was cultivated for fodder and 'ghee' was available in abundance. According to J. Xavier,[b] in Agra region 'butter with rice, millet and pulses formed the food of the common people and there was no one in Agra who did not eat it'.

Another point of our interest is that from all accounts area cultivated under *bajra* at that time was much smaller than what it is today.

Pulses

Under the name pulses come a number of leguminous seeds which are eaten as a source of vegetable protein. During Akbar's reign many of these were grown and tax was collected on their production. These are given below with their Persian, Hindusthani and English, and Latin names:

Persian names	*Hindusthani and English names*	*Latin names*
Maash	Mung	*Phaseolus aureus* Roxb.
Maash siah	Urd	*Phaseolus mungo* Roxb.
Moth	Meth kalai, kheri	*Phaseolus aconitifolius* Jacq.
Lobya	Lobia, cowpea	*Vigna sinensis* (L.) Savi ex Hassk.
Kult	Kulthi, horse gram	*Dolichos biflorus* L.
Adas	Masur, lentil	*Lens culinaris* Medic.
Nakhud	Chana, gram, chick pea	*Cicer arietinum* L.
Mashang	Mattar, garden pea	*Pisum sativum* L. var. *Arvense poir*
Khesari	Grass pea	*Lathyrus sativus* L.

Oil-seeds

Many crops were cultivated for oil-yielding seeds. The important ones were linseed (*Linum usitatissimum* L.), safflower (*Carthamus tintorius* L.), Sesame or *til* (*Sesamum indicum* L.). Then mustard and *toreya* are also mentioned. *Toreya* is *Brassica campestris* L. var. *toria* Dutt and Full, while mustard includes a number of species and varieties, such as *B. compestris* L. var. *dichotoma* Watt, the *kalisarson*; *B. compestris* L. var.

[a] Habib, p. 54; Chalam and Venkateshwarlu, pp. 386–428.
[b] Sarkar (J.), pp. 69–117.

sarson Prain, yellow *sarson*; *B. hirta* Moench, white mustard, *sofed rai*; *B. juncea* (L.) Czern and Coss, *rai*; *B. napus* L., the *kalisarson*, and *B. nigra* Koch, the *kalirai*. It is quite possible that the entire lot of oil-yielding mustards was grouped together at that time for the purpose of taxation. We know now that scientific classification of plants was then absent.

Cash Crops

Under cash crops, sugar-cane was extensively cultivated all over the country. 'In Bengal sugar-cane was pre-eminent both in volume of output and quality.'[a] Cultivation of cotton (*Gossypium arboreum* L.) has been reported in smaller areas than that of the sugar-cane. Its cultivation was, however, not restricted to the so-called cotton tract, but beyond it. North India used to grow cotton in a fairly large quantity. Surprisingly Bengal is reported to have produced an important crop of cotton which is not the case today. The reason might have been lack of proper transport. Bengal was at that time at the height of production of muslin cloth which necessitated easy accessibility to cotton. During the latter part of the Muslim period, indigo (*Indigofera tinctoria* L.) was an important cash crop in great demand for internal use as well as for export.[b] Incidentally, this dye-yielding plant of the seventeenth century had its own history written in volumes in commercial literature of the time. The best quality came from Bayana tract near Agra. Inferior quality grew in the Doab, Khurja and Koli (Aligarh). A place called Sarkheja, near Ahmedabad, has also the reputation of producing good quality indigo. The indigo grown in the south (Telingana) was considered to be of medium quality. In fact, *indigo* plantation was quite common from Bengal to Khandesh. Of interest from a scientific point of view is that with the disappearance of cultivation of indigo, its adverse effect on the fertility of soil for growing wheat and other spring crops was realized. We now know about the nitrogen fixation ability of the roots of indigo plant but in the sixteenth and seventeenth centuries this knowledge was not available. But all the same cultivators did realize that something went wrong with the soil if indigo was not grown. Another dye-yielding plant was known during Akbar's time. It was called *al* (*Morinda tinctoria* Roxb.) and produced a red dye. Cultivation of both these plants was stopped when use of synthetic dyes came into vogue.[c]

Henna or *mehndi* (*Lawsonia inermis* L.) is another dye-yielding plant that was taxed during Akbar's reign. Leaves of this plant are crushed into a thick paste and applied by women and girls on their hands and feet. When removed after half an hour or so, hand and feet retain a red colour. This is still the practice in villages, while the women of the urban area use modern nail-paints. Again, *pān* (*Piper betle* L.), which is chewed along with areca nut (*Areca catechu* L.) and other ingredients, was taxed by the Emperor.

[a] Habib, p. 40.
[b] Sarkar (J.), pp. 71, 78, 93.
[c] Habib, pp. 42–44.

Of these, almost all are cultivated at the present time.[a] A point to note here is that these small cereals were cultivated in those days because either they were eaten by the poorer sections of people or they were used as fodder. It is most likely that the latter was the case, because it is repeatedly mentioned that pasture covered extensive area of the land. For instance in Bengal, where there are now few pasture lands, an extensive area was cultivated for fodder and 'ghee' was available in abundance. According to J. Xavier,[b] in Agra region 'butter with rice, millet and pulses formed the food of the common people and there was no one in Agra who did not eat it'.

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[a] Habib, p. 54; Chalam and Venkateshwarlu, pp. 386–428.
[b] Sarkar (J.), pp. 69–117.

tectorius Soland ex Parkinson). The next mention of flowers is by Jahangir (1605–27) in his memoirs.[a] Here not only the beautiful flower bearing plants were mentioned, in some cases, the colour of sepals and petals was also described. He gave the locality where he saw these flowers. Of the many Persian names given by him, the following have been traced to their Latin names.

Persian names	*Hindusthani and English names*	*Latin names*
Kaner	Oleander	*Nerium indicum* Mill.
Dhak	Dhak, palas	*Butea frondosa* Roxb.
Nilufar	Kamudini, bhamber, lotus	*Nymphaea stellata* Wild.
Kanwal	Padma, Indian lotus	*Nilumbo nucifera* Gaertn.
Gul-i-champah	Champa	*Michelia champaca* L.
Gul-i-keora	Keora, screw-pine	*Pandanus tectorius* Soland ex Parkinson
Rai bel	Jasmine	*Jasminum sambac* (L.) Ait
Chambeli	White jasmine	*Jasminum multiflorum* (Burm. f.) Andr.
Maulsiri	Spanish cherry	*Mimusops elengi* L.
Seoti	Dog-rose	*Rosa glandulifera* Roxb.
Gul-i-bulanik	Crowned imperial lily	*Fritillaria imperialis* L.
Argwani zard	Buttercup	*Ranunculus* sp.
Nargis	Narcissus	*Narcissus poeticus* L.
Banafshah	Violet flower	*Viola odorata* L.
Gul-i-badam	Almond flower	*Prunus amygdalus* Batsch.
Gul-i-shaftalu	Peach flower	*Prunus persica* (L.) Stakes.
Chhui-mui	Lajwanti	*Mimosa pudica* L.
Saffron	Zaffran	*Crocus sativus* L.

Besides, Jahangir says, 'Atr of roses—the most excellent perfume—was discovered in my reign. The mother of Nurjahan Begum conceived the idea of collecting the oil which rises to the surface when rose-water is heated and, this having done, the oil was found to be most powerful perfume.'[b]

As regards fruit trees, mango (*Mangifera indica* L.) was especially popular. There is, however, no mention of the varieties of mangoes that were in existence at that time. Could it be possible that development of different varieties of mango was done after the Muslim period? In addition to mango, Amir Khausru[c] mentions different varieties of grapes (*Vitis vinifera* L.), dates (*Phoenix* spp.), pomegranate (*Punica granatum* L.), plantains (*Musa paradisiaca* L.), lemons (*Citrus* spp.), *khirni* (*Manilkara*

[a] Alvi and Rahman (2), pp. 92–102.
[b] Elliot and Dowson, p. 101.
[c] Ashraf, p. 201.

hexandra (Roxb.) Dub.), jaman (*Syzygium cumini* (L.) Skeels), jack-fruit (*Artocarpus heterophyllus* Lamk.) and many others. Coconuts (*Cocos nucifera* L.) were abundant on the coastal area.[a] Feroz Shah Tughluk carried out extensive operation to establish fruit gardens in and near Delhi. According to his chronicler, he laid out as many as 1,200 gardens in the Delhi area and 43 in Chitore. Special attention was paid to the cultivation of pomegranate in Jodhpur, fruits from which place were considered to be better than those from Persia. In Babur's memoirs[b] he mentioned some of these fruits, and also *imli* (*Tamarindus indica* L.), *badhil* (*Artocarpus lakoocha* Roxb.), *ber* (*Zizyphus mauritiana* Lamk.), *karonda* (*Carissa carandas* L.), *pani-amla* (*Flacourtia jangomas* (Lour) Raeusch), *guler* (*Ficus glomerata* Roxb.), *amleh* (*Emblica officinalis* Gaertn.) and *chirunji* (*Buchanania lauzan* Spreng). In addition, Babur listed a large number of *Citrus* but to determine their identity under present classification is almost an impossible task.

By the time of Akbar's reign, a considerable improvement had been brought about by introducing new stock from Central Asia and Afghanistan. For instance, cherries were not grown in Kashmir before Akbar's time. Grafting of superior stock was also done to improve the local varieties. At this time plantation of temperate climate fruit trees was mostly confined to imperial gardens and those of the noblemen of the country. It was Shajahan who 'lifted this ban for both the select and the masses'.[c] From all accounts this wider application brought about extensive cultivation of fruit trees in the country.

Jahangir[d] recorded his observations on fruit trees, some of which are listed below:

Local names	*English names*	*Latin names*
Shah alu, gilas	Sweet cherry	*Prunus avium* L.
Zard alu	Apricot	*Prunus armeniaca* L.
Naspati	Pear	*Pyrus communis* L.
Seb	Apple	*Malus sylvestris* (L.) Mill.
Amrud	Guava	*Psidium guajava* L.
Angur	Grape	*Vitis vinifera* L.
Anar	Pomegranate	*Punica granatum* L.
Tarbuz	Water-melon	*Citrullus vulgaris* Schrad ex Eckl. and Zeyh.
Kharbuza	Musk-melon	*Cucumis melo* L.
Tut	Mulberry	*Morus alba* L.
Askhin	Strawberry	*Fragaria vesca* L.
Alu balu	Sour cherry	*Prunus cerasus* L.
Shaftalu, aru	Peaches	*Prunus persica* (L.) Stokes

[a] Ashraf, p. 201.
[b] King (L.), II, pp. 225–37.
[c] Habib, p. 51.
[d] Alvi and Rahman (2), pp. 106–109.

Gardens

Much has been written about the Mughal gardens by both Indians and foreigners but before the Mughals came into the scene considerable attention had been paid by the kings of Delhi Sultanate and the Hindu kings. Babur's remarks[a] on this aspect of Indian culture, when he reached Delhi, seem to be in indiscordance with the available facts. That his son Humayun appreciated the layout of gardens and buildings of Bengal to make him overstay there is enough proof against Babur's remarks. Akbar and his successors made many improyements in this respect at Delhi and Agra and these gardens even now are considered worth visiting by Indians and foreigners.

Gardens at that time contained not only flower plants but also fruit trees. The latter used to bring a considerable income to the exchequer. We also know of the renowned imperial gardens at Agra where all sorts of exotic trees were planted and maintained under the personal supervision of the emperors.

Introduction of Plants

Books on Indian economic plants give many plants which have been introduced in the country from outside. It is not always possible to find out when and by whom each of these plants was introduced. There are, however, records available indicating when a few of them were introduced during the Muslim period. Mention has already been made of cherry (*Prunus avium* L.) which was introduced in Kashmir from Persia during Akbar's time. Tobacco (*Nicotiana tabacum* L.) came to India from South America via Arabia. Pilgrims from south India are said to have brought it with them when they returned home after Haj. Tobacco was introduced in north India during Akbar's time when one of his lieutenants in the south brought this as a present for the Emperor. Akbar did not indulge in tobacco-smoking except for once. His son Jahangir passed orders for the prohibition of tobacco. But it was an ineffective royal order; people went on smoking but not publicly. Gradually its cultivation spread from west to east and south to north.

Another important plant introduced in the country was pineapple (*Ananas cosmus* (L.) Merr.) by the Portuguese in the west coast during the sixteenth century. It became a very popular fruit to grow. Its cultivation spread rapidly from Gujarat to Bengal. During Jahangir's time many thousands of this plant were grown in the imperial garden at Agra. To do this an artificial, moist tropical environment had to be developed—a rather expensive affair. Other South American plants of importance introduced about this time were papaya (*Carica papaya* L.) and cashewnut (*Anacardium occidentalis* L.), but the spread of their cultivation was much slower than that of the pineapple. It was only in the seventeenth century

[a] King (L.), II, p. 156.

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[d] Alvi and Rahman (2), pp. 106–109.

e drogas cousso medicinalis da India compostos pelle, in which he included information on

(*a*) the eastern drugs that the Arabs sent westwards in trade;
(*b*) the samples used in India that were new to the men in the West;
(*c*) information on local fruits, narcotics, etc.

The Dutch in Malabar (1667–1750)

The Dutch East India Company in Malabar (1667–1750) had some men who took considerable interest in the vegetation of the area they were working in. Of these, Heinrich Van Rheede tot Draakenstein, who was appointed Governor of the Dutch possessions in 1667, was a keen botanist. During 1674 and 1675 he collected specimens of plants with the help of the local people and sent them to Cochin, where drawings were prepared by Mathaeus. Corresponding descriptions were written in Malabar language, which were first translated into West European language and then to Latin. This work by Van Rheede was published between 1686 and 1703 at Amsterdam in 12 folio volumes with 794 plates. Sir William Jones referred to the publication as interesting. He said, 'When we complain, and myself as much as any, that we have leisure in India for literary and philosophical pursuits, we should consider that Van Rheede was a nobleman at the head of an Indian government and that he fully discharged all the duties of his important station, while he found leisure to complete those 12 large volumes, which Linnaeus himself pronounces accurate.'

Another important work, which originated from this Dutch settlement, was the writing by George Everhard Rumphius. The manuscript was written in Dutch and remained in the possession of the Dutch Company for many years. Then Professor John Burman of Amsterdam rescued it. After editing, it was published in 1757 in six volumes. Latin translation was provided and it contained 696 plates.

Paul Herman was appointed under Van Rheede for botanical work and was posted in Ceylon. Herman's plant collection went to Leiden and was worked out by him. The results were published in 1717 entitled Herman's *Museum Zeylanicum.* Later in 1737, John Burman published his *Thesaurus Zeylanicus* based on Herman's specimens. Herman's herbarium was rediscovered by M. Gunthar, an apothecary to the king of Denmark, who sent it to Linnaeus. In 1747 Linnaeus published *Flora Zeylanica* in which he described new genera and included Malabari and Sinhalese names. This is an example of restoration of learning of the eighteenth century.

Protestant Mission in the Dutch Settlement in Tranquebar (1668–1834)

There was another centre of Dutch activity in India on botany. In 1768 John Gerard Koenig was appointed at the Tranquebar Mission in south. He was a missionary surgeon and had his early training in Uppsala

in Sweden under Linnaeus. Koenig was an enthusiastic collector of natural science products. He not only made a serious study of the flora of Madras coast but also sent dry plants to Sir Joseph Banks and his teacher Linnaeus. The latter gave special place to these plants in his herbarium.

It must be pointed out here that Koenig was the first botanist who introduced Linnaean system of classification of plants in India. Before this the classification was mainly based on uses of plants without giving serious consideration to how flowers and other parts were arranged in a plant.

Missionaries gathered round Koenig's 'United Brotherhood', a society established for the promotion of botanical studies in India. Members of the Brotherhood included many missionaries of Tranquebar such as Heyne, Klein, Rottler, William Roxburgh, William Jones and Buchanan Hamilton.

Koenig, after 10 years with the Mission, transferred his services to the Nawab of Arcot and then to the East India Company. He was sent to Siam and the Malay Peninsula to ascertain if Siamese cardamom could be grown in south India. He became ill and retired in 1785.

Systematic botanical investigations were continued later by several European naturalists in different parts of India. Of them, special mention may be made of William Roxburgh, William Carey, Nathaniel Wallich and George King. The Royal Botanic Garden came into being as early as 1787 through the efforts of Robert Kyd. The part played by this garden, botanical investigations in the nineteenth century, the formation of the Botanical Survey of India and related matters are discussed in chapter 10.

8 ZOOLOGY

J. L. BHADURI
K. K. TIWARI
BISWAMOY BISWAS

ANCIENT Indians, like their contemporaries in the West, had collected considerable information about the living world, although their efforts in this field have generally passed unnoticed in books on the history of biology by such modern authors as Nordenskiold, Locy, Bodenheimer and several others. One of such modern historians of biology remarks: 'The civilized peoples of Eastern Asia, the Hindus and Chinese, have likewise contributed very little of importance to the development of the science of biology. Hindu Science, indeed, especially in the sphere of mathematics, reached a high standard...'[a] We believe that remarks and opinions of this kind, due probably to the lack of knowledge of Sanskrit and other classical languages of India on the part of Western historians of biology, now require revision. We have abundant evidence, albeit scattered in archaeological and literary records, of the interest and curiosity of ancient Indians in the living world around them leading to a large mass of facts and ideas comparing favourably with similar efforts made contemporaneously by peoples of other culture areas of the world.

PREHISTORIC PERIOD

Neolithic Haematite Drawings of Animals

The earliest concrete evidence of interest in animal life is furnished by the 'ruddle' or 'haematite drawings' in caves or sheltered rocks, made by the neolithic men in India (Fig. 8.1). That these neolithic dwellers of the subcontinent, out of sheer necessity for existence, must have acquired familiarity with animals and plants is self-evident. Keen naturalists as they were, they must have memorized shapes and forms of animals hunted

[a] Nordenskiold, p. 7.

in Sweden under Linnaeus. Koenig was an enthusiastic collector of natural science products. He not only made a serious study of the flora of Madras coast but also sent dry plants to Sir Joseph Banks and his teacher Linnaeus. The latter gave special place to these plants in his herbarium.

It must be pointed out here that Koenig was the first botanist who introduced Linnaean system of classification of plants in India. Before this the classification was mainly based on uses of plants without giving serious consideration to how flowers and other parts were arranged in a plant.

Missionaries gathered round Koenig's 'United Brotherhood', a society established for the promotion of botanical studies in India. Members of the Brotherhood included many missionaries of Tranquebar such as Heyne, Klein, Rottler, William Roxburgh, William Jones and Buchanan Hamilton.

Koenig, after 10 years with the Mission, transferred his services to the Nawab of Arcot and then to the East India Company. He was sent to Siam and the Malay Peninsula to ascertain if Siamese cardamom could be grown in south India. He became ill and retired in 1785.

Systematic botanical investigations were continued later by several European naturalists in different parts of India. Of them, special mention may be made of William Roxburgh, William Carey, Nathaniel Wallich and George King. The Royal Botanic Garden came into being as early as 1787 through the efforts of Robert Kyd. The part played by this garden, botanical investigations in the nineteenth century, the formation of the Botanical Survey of India and related matters are discussed in chapter 10.

species of animals associated with the lives of prehistoric peoples. The total number of species identified is 92. Mammals represented by 41 species top the list. Next in order are molluscs represented by 31 species, including some marine and land forms and reptiles by 12 species, while fishes and birds, of which only five and two species respectively have so far come to light, are scantily represented. Barring molluscs, the only other invertebrate occurring at Mohenjo-daro (but not reported from other places) is coral, *Favia fabus* (Forskål). For a full list of species, Nath's work may be consulted.[a] We shall, however, restrict our remarks to a brief discussion of the faunal characteristics.

The rich yield of animal remains comes from Mohenjo-daro and Harappa. Sewell and Guha[b] have listed 37 species from Mohenjo-daro, while Prashad[c] has identified 30 species from the remains obtained from Harappa, among which many are common to both sites.

The identified mammals from prehistoric animal remains fall under three major categories, viz. domestic, semi-domestic or the wild forms habitually associated with vicinities of human dwellings, and wild beasts.

The domestic animals are the humped cattle, buffalo, horse, domestic ass, sheep, goat, elephant, camel, pig, dog and cat. Of birds, remains of only two species are known with certainty; the fowl was definitely domesticated and the black partridge might have been so. The presence of so many domestic species in prehistoric India is not surprising. It is now universally accepted that the domestication of animals either preceded or went side by side with the transition of man from a nomadic hunting and root-gathering stage to a farming one. The people had already taken to agriculture and had domesticated the species mentioned above. The commonest domestic animals whose remains have turned up at several prehistoric sites in India were the humped cattle, buffalo, sheep, goat and pig. The elephant seems to have been tamed fairly early as its remains have been found at both Harappa and Mohenjo-daro. The ass was a common domestic animal but not everywhere. The horse appears to have come into the picture later as its remains are not found in the earlier stratifications. This animal was very popular among the later Aryans who used it for drawing chariots, for riding and as a sacrificial animal. The dog and the cat are not plentifully represented, though they might have been popular. There are archaeological indications that the people of Harappa were familiar with at least two kinds of dogs, one of which, a mastiff, had been a locally restricted breed (Fig. 8.2).

Of the remains of other animals so far found, which were not truly domesticated in the economic sense but moved freely among human settlements or at their outskirts in prehistoric times, mention may be made of the rat, the mongoose and the shrew. The jackal and the wolf had been the prowlers in forests or scrubs skirting the inhabited areas.

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[a] Nath, pp. 1–63.
[b] Sewell and Guha, pp. 649–73.
[c] Prashad (1), pp. 1–62.

The wild life apparently familiar to these people consisted of the elephant, rhinoceros, wolf, jackal, nilgai, gaur (Indian bison), buffalo and a few species of deer like the hangul or Kashmir stag (whose horns

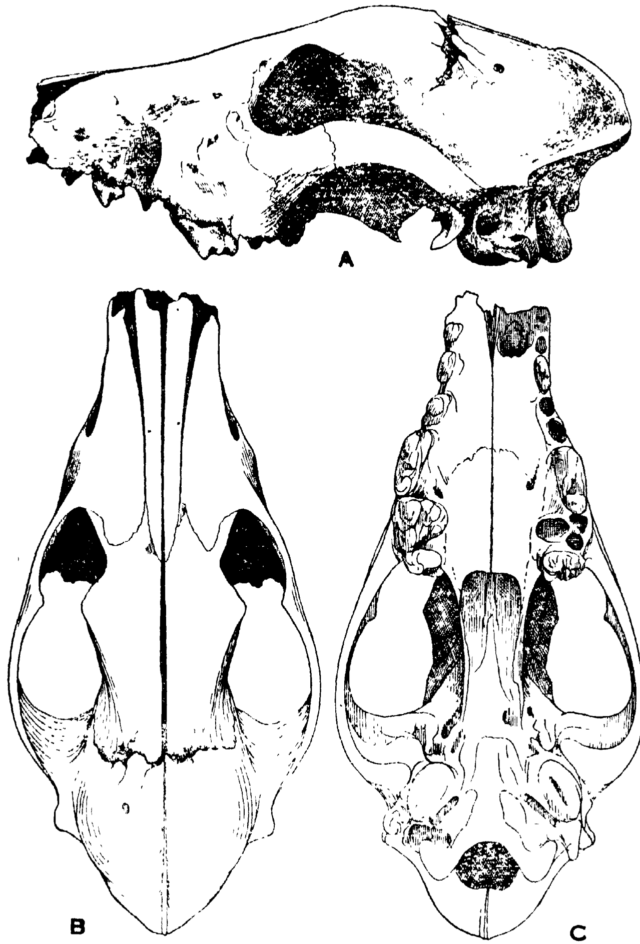


FIG. 8.2. Skull of the Harappan dog, *Canis tenggeranus harappensis* Prashad. A, lateral; B, dorsal; C, ventral views.

were perhaps imported by the people of Harappa along with those of the sambhar and chital for medicinal purposes),[a] chital, sambhar, barasingha, four-horned antelope, blackbuck and hog deer. The sambhar, barasingha

[a] Sewell and Guha, p. 671.

and chital, specially the last, were fairly widespread as their remains had been found in several prehistoric and historic sites from different parts of India.

The abundant molluscs which included many marine forms like *Xancus* (Chank shell) and *Arca* (Arc shell), etc., were apparently used for food (along with the domestic animals) as well as for ornamental purposes. The remains of bangles and their fragments at Harappa and Mohenjo-daro, and cores of shells from which these had been sawn off, point to the existence of a well-developed bangle industry at those sites. Possibly several species of turtles recovered at many sites might also have served ornamental purposes in addition to fulfilling the dietary requirements.

Among the 12 species of reptiles, eight belong to tortoises and turtles in seven genera, while the remaining ones are the crocodile, gharial and two species of monitor lizards.

Fishes are scantily represented and their remains do not furnish their identity with certainty. There are carp and other 'teleostean' remains, *Rita rita* and *Wallago* sp., both freshwater forms, and *Arius* sp., an estuarine fish. The scantiness of fish remains, however, may not indicate paucity or lack of interest in fish. There is definite evidence, furnished by the unearthing of several fish-hooks from these sites, which indicate that angling was a common pastime, as also the netting of fishes.[a]

Strangely enough, no remains of the tiger and lion are found though the former was by no means uncommon to the Harappans as we shall see later. The occurrence of rhinoceros remains at Harappa and Mohenjo-daro is interesting indeed. It has also been discovered at Lothal in Gujarat and formed the subject of neolithic haematite drawings in Mirzapur. The distribution of this dweller of marshy forest lands is now severely restricted, though only in historic times it was hunted by the Mughal Emperor Babur at Peshawar in the former North-West Frontier Province of undivided India. Judged from the archaeological finds and from references in the Vedic and the Puranic texts, it is apparent that rhinoceros was a fairly common animal in certain parts of India until recent historic times.

The animal remains dug up from the prehistoric sites give concrete evidence of the association of the people with the animal world and of the extent to which these were harnessed in the service of man. Some idea as to the impact of animal life on the prehistoric Indian culture and on the thought processes of these people can also be gathered from the glyptic art represented on seals, paintings on pottery and animal figurines and toys.

Large numbers of steatite seals excavated from Harappa and Mohenjo-daro bear engravings of animals in profile with inscriptions in a pictographic script still remaining undeciphered. Some of the animals depicted—the unicorns and chimaeras—are apparently mythical, but others are immediately recognizable as beasts obviously familiar to the artists of those times. The dexterity and sureness of touch with which many engravings have

[a] Sarkar (H.), pp. 133–34.

been executed are indeed commendable, specially the humped bull, in which even the wrinkles on shoulders and dewlaps have been faithfully reproduced.

The recognizable animals on seals from Mohenjo-daro, according to Mackay, are the short-horned bull (a smaller humpless breed), zebu or

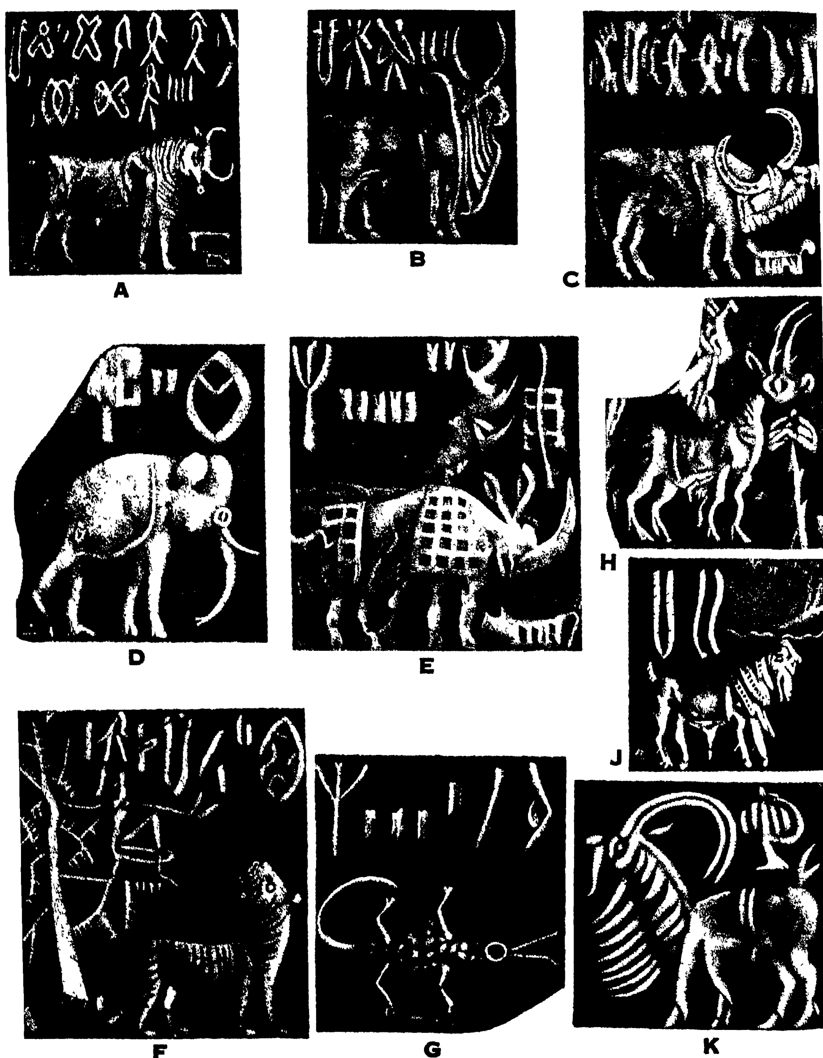


Fig. 8.3. Representation of animals on seals of Mohenjo-daro. A, short-horned bull; B, Indian humped bull; C, buffalo; D, elephant; E, rhinoceros; F, tiger; G, gharial; H, chinkara; J, domestic goat; K, wild goat (after Mackay, 1931, 1938).

Indian humped bull or brahminy bull (*Bos indicus*), buffalo (*Bubalus bubalis*), elephant (*Elephas maximus*), Indian one-horned rhinoceros (*Rhinoceros unicornis*), tiger (*Panthera tigris*), gharial (*Gavialis gangeticus*) and antelope (blackbuck ?). Further excavations from the same site have also unearthed a few seals with engravings of a frog (?), the chinkara or Indian gazelle (*Gazella gazella bennetti*) and the goat (*Capra hircus aegragus*)[a] (Fig. 8.3).

Majority of the seals excavated from Harappa[b] bear engravings identical with those from Mohenjo-daro, but on some are carved animal forms not represented at the former site. These are the gaur or Indian bison (*Bos gaurus*), eagle (?) (Fig. 8.4) and a hare (?). In addition, miniature seals representing the gharial, fish and tortoise are also available from Harappa.

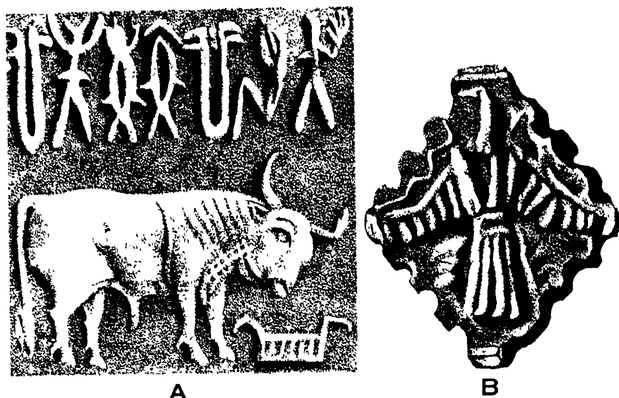


FIG. 8.4. Representation of animals on seals of Harappa. A, gaur; B, eagle (?) (after Vats, 1940).

Judging from the frequency of reproduction on seals, it seems that among the recognizable animals the most popular (next to unicorn) are the bulls which are represented both by a smaller, short-horned, humpless variety (only found in the seals at Mohenjo-daro) and by the brahminy bull or the Indian humped cattle. The short-horned bull is invariably carved in a characteristic stance, the head lowered and slightly twisted to one side, as if in an angry mood and just about to charge.[c] In most cases the heavy wrinkles on shoulders, and sometimes the dewlaps, are also reproduced with great fidelity. The sureness of touch with which these are executed leaves no doubt as to the identity of the zebu. The elephant, next to the bull in order of popularity, was certainly tamed by the Indus

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[a] Mackay (1), pp. 385–92; Mackay (2), I, pp. 326–35.
[b] Vats, I, pp. 300–309; *vide* also pp. 451–58.
[c] Mackay (1), p. 385.

Valley people, and has been represented on the seals by two types, one with flat back, square head and stout legs, and the other less heavily built and with a sloping head.

Among the wild animals only the tiger, rhinoceros, gaur, blackbuck (?) and chinkara appear to have impressed the Indus Valley artists sufficiently to warrant a place on the seals. The tiger, fairly well-represented, is of special interest on two seals, where the animal is depicted as standing below a tree, tail curled up and turned behind intently watching a man perched safely above on the tree (Fig. 8.3F). Apparently, such a scene might not have been an unusual one during those days.

Many animals are shown along with a manger, or tethered, indicating domestication or a state of captivity. The accuracy with which several animals are depicted on the seals reveals the intimate acquaintance of the artist with them, an acquaintance which could have been resulted only from close and sustained observations, and from a real understanding of the animal life.

A remarkable feature is the non-representation of the cow on the seals. The animal was surely as abundant as the bull, yet there is not one figure depicting it. In strange contrast to this, as we shall see further on, the cow assumed importance among the Aryans who inhabited India in later times. Similarly, the absence of the lion, another well-known animal of the Vedic Indians, is conspicuous. It is difficult to explain why it is so; perhaps it may have something to do with their traditional beliefs rather than zoology.

Turning to the other forms of animal representations, we find the list of species further enhanced by the figurines, toys and paintings on pottery. Animal figurines are found in large number, apparently made as toys for children, containing some curious inconsistencies like the hare with a long tail or cattle with a truncated tail. As on seals, the most popular objects for figurines are the short-horned bull and the brahminy bull, followed by the rhinoceros. The ram, not depicted on the seals, appears to be popular as figurines.

Animals represented through this form of art at Mohenjo-daro are the two kinds of bulls, rhinoceros, dog, mastiff, elephant, gharial, hare, monkey, turtle, antelope (blackbuck ?), horse (?), pig (rare), sheep, goat, buffalo and other unidentified species. Birds like the dove, domestic fowl, peacock, bunting (?), duck and goose are also represented[a] (Fig. 8.5).

The Harappa toys, as Vats[b] has pointed out, contain representations of the two bulls, rhinoceros, goat and ram. The tiger (which is found only on the seals in Mohenjo-daro), elephant and pig are also depicted. The monkey and possibly the cat were also known and squirrels and reptiles were very popular. The mongoose, snake and pangolin also figure. The crocodile, turtle, and the fish among aquatic animals, and the duck, peacock,

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[a] Mackay (1), pp. 394–96.

[b] Vats, I, pp. 300–309, 452.

hen, kite, pigeon, sparrow, dove, parakeet and owl among birds find representation in the toy art (Fig. 8.6). There is also a toy that looks much like a grasshopper.

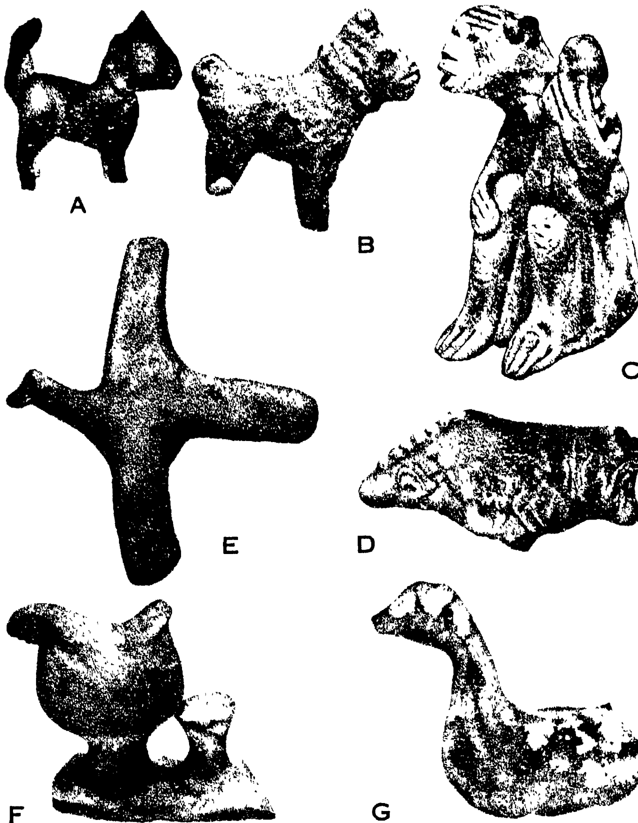


FIG. 8.5. Figurines, toys, etc., of Mohenjo-daro. A, dog; B, mastiff; C, monkey; D, pig; E, dove; F, domestic fowl; G, goose (after Mackay, 1938).

The artistic representations of animals, associated with pottery, start coming up in archaeological finds belonging to pre-Harappan cultures in India. The excavations made by the Archaeological Survey of India at Kalibangan, Ganganagar district, Rajasthan, are specially interesting in this context. The animal motifs represented on pottery from this site include some excellent, stylized figures of the blackbuck, chinkara (?), and an incomplete, but otherwise highly realistic drawing of a duck (Fig. 8.7).[a]

[a] *Indian Archaeology, 1962–63*, p. 24.

Another unique feature in this pottery is the representation of a spider and scorpion, two ubiquitous creatures of India, which do not find place in any other ware excavated so far from different parts of India.

The decorations found on pottery from Harappa and Mohenjo-daro as well as from other areas of the north-west, like Rana Ghundai, Nāl, etc., contain several animal motifs and panels depicting natural scenery

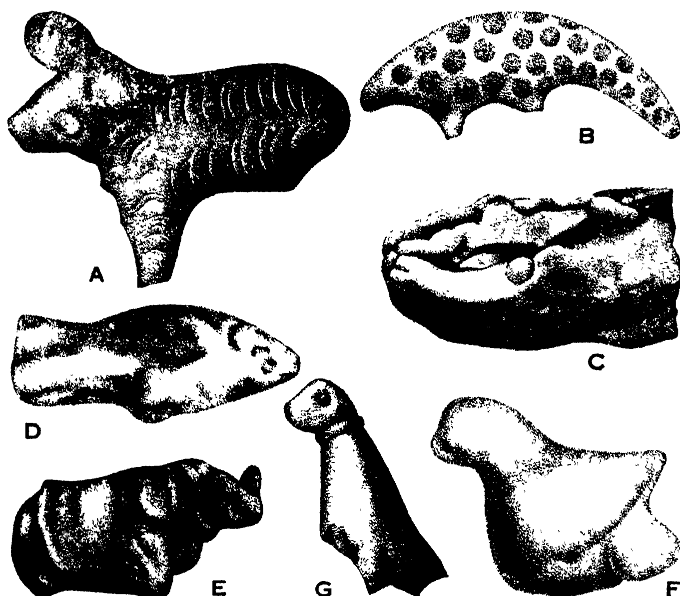


FIG. 8.6. Toys, etc., of Harappa. A, ram; B, pangolin; C, crocodile; D, fish; E, rhinoceros; F, pigeon; G, parakeet (after Vats, 1940).

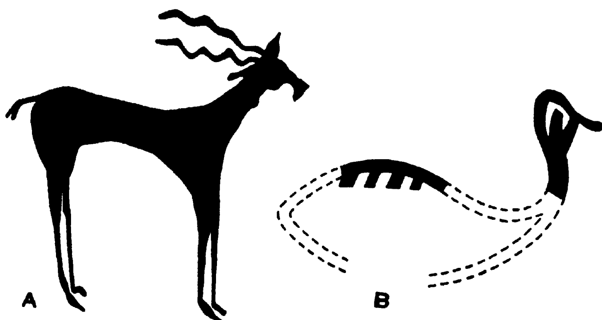


FIG. 8.7. Animal paintings on pottery of Kalibangan, Rajasthan. A, blackbuck; B, duck (after *Indian Archaeology, 1962–63*).

with animal and plant life. Animal designs on Mohenjo-daro pottery include the ibex (which must have been fairly well known to the inhabitants there), antelope, jackal, bird, snake and lizard (perhaps the monitor). Figures on faience wares depict the dove, parakeet, peacock, masks of a panther-like animal, squirrel (seated on its haunches with forepaws in the mouth, as if eating), mongoose, hare, elephant, monkey, humped bull and the short-horned bull.

Harappa wares also display similar representations of animals. In addition, many sherds with plain and painted pottery show decorative panels with animal motifs (Fig. 8.8). Thus, a decorated pot shows two goats, a highly conventionalized representation of a peacock and a grasshopper between the feet of one of the goats. Another ware depicts a she-goat suckling her young and a peacock, while a third one shows a peacock holding a plant in its beak and some crude caricatures of small birds.

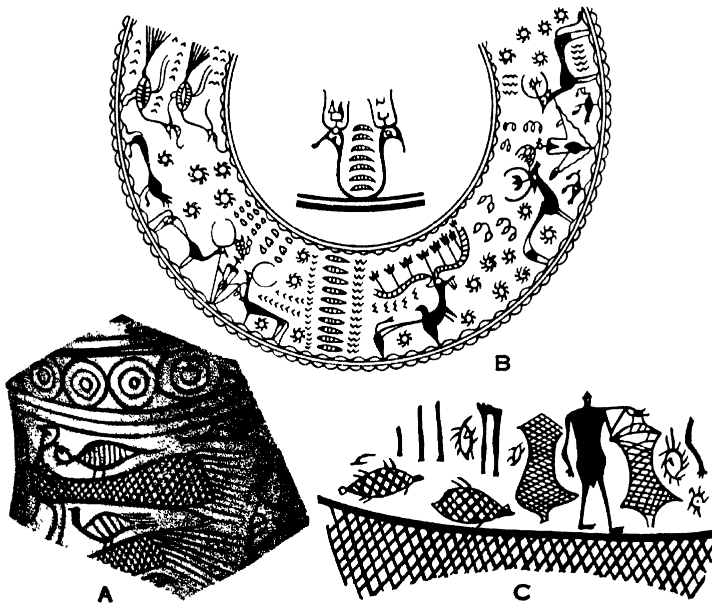


FIG. 8.8. Animal motifs on Harappa wares. A, peacock with other animals; B, ibex; C, fisherman with net and pole (after Vats, 1940).

Most interesting is a sherd depicting 'a fisherman carrying two nets suspended from a pole across his shoulders, with a fish and what is probably a turtle near his feet, which rest on a cross-hatched band, presumably the river by which he is walking'[a] (Fig. 8.8C).

[a] Piggott (2), p. 193.

Examples of decorated pottery with naturalistic representations are available from other prehistoric sites adjoining Harappa-Mohenjo-daro culture in Baluchistan.

The Kulli wares from Kolwa in south Baluchistan contain natural representations of animals and plants on a frieze between zones of non-representational motifs. 'The frieze represents a standard scene, in which two animals, usually humped cattle but sometimes felines, dominate in grotesquely elongated form, a landscape with formalized trees and sometimes ancillary rows of diminutive, very stylized goats.'[a]

Some very interesting pottery remains with fish paintings executed in polychrome have been excavated from Nāl (Jhalawan Division of Kalāt State, Baluchistan). Hora[b] has attempted to identify the fishes represented on the 4,000-year-old Nāl ware, which he assigns to seven genera, namely *Garra*, *Crossochilus*, *Cyprinon*, *Tor*, *Nemachilus*, *Botia* and *Glyptothorax* (Fig. 8.9). The attempted identification is indeed a tribute to the Nāl artists for realistic accuracy. If Hora's identifications are correct,

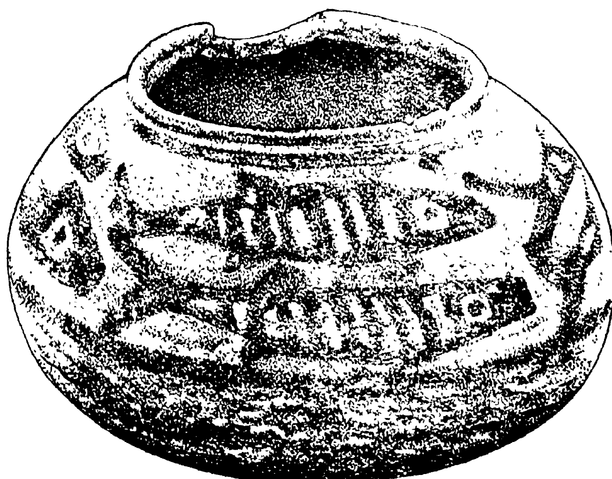


FIG. 8.9. Polychrome painting on Nāl ware showing *Nemachilus*-like fish (after Hora, 1957).

and they appear to be so, the pottery fish designs may throw some light on the climatic conditions then prevailing in Baluchistan. Hora rightly concludes that Baluchistan, now an arid area, might have had more rainfall and voluminous perennial streams during those times, since at least three of the fish motifs on the pottery represent genera which live in such streams.

[a] Piggott (2), p. 100.
[b] Hora (6), pp. 78–84.

No account of animals that caught the attention of prehistoric Indians can be complete without a reference to the mythical forms, specially the 'unicorn', depicted on seals from Harappa and Mohenjo-daro (Fig. 8.10A). The fact that 312 seals out of 387 excavated from Mohenjo-daro in the

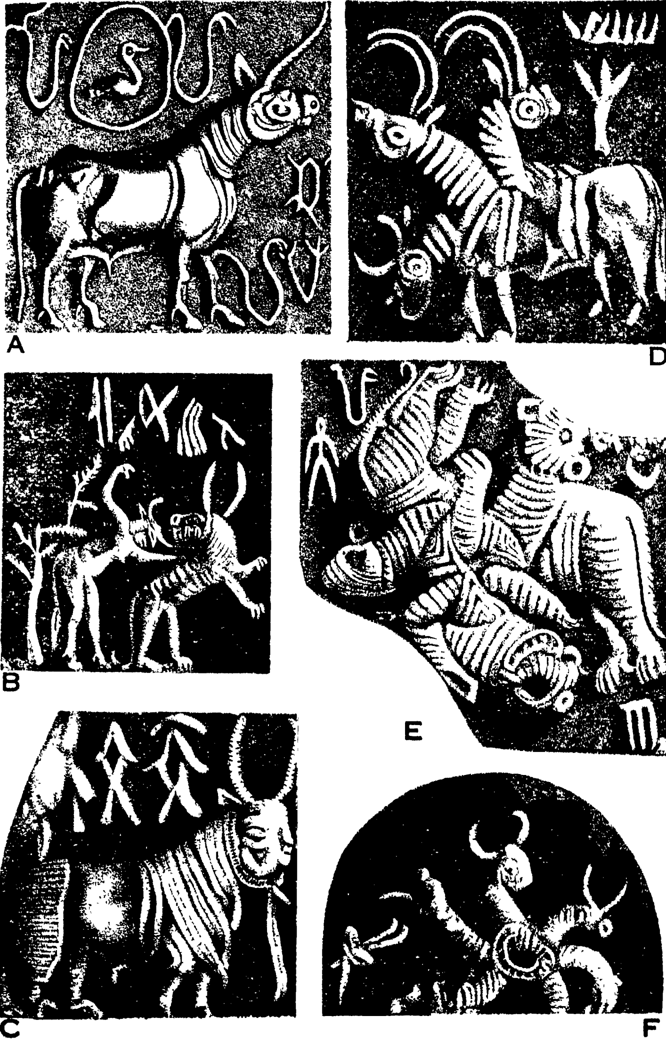


FIG. 8.10. Mythical animals depicted on seals of Mohenjo-daro. A, unicorn; B, human figure with hoofs, horns and tail; C, ram+bull+man+elephant+tiger; D, three-headed beast; E, 'triskillon'; F, heads and necks of six animals radiating from a common ring (after Mackay, 1931).

first exploration[a] depict this fabulous animal indicates the importance it might have had in the traditional beliefs of these peoples. Use of animal symbols as totems is known throughout the world since the beginning of human cultures and animals have indeed played a very important role in conditioning certain aspects of instinctive behaviour in man. No wonder, this mythical animal—the unicorn (so called for want of a better name)—dominated the glyptic art of Harappa and Mohenjo-daro, though the reasons for this may never be known until one could decipher the script on the seals. The unicorn, always depicted in profile like other totems, is a male beast with one horn, body of a heavily-built antelope or of an ox with a long tufted tail. The horn is either smooth or transversely ridged (so unlike that of an ox) and the ears are long and pointed (as in antelopes). Apparently it is a composite animal belonging to the realm of legends. Indian mythological lore abounds in such fabulous creatures. Besides the unicorn, there are chimerical beasts represented on some seals. One such seal depicts a human figure with hoofs, horns and tail of a bison (Fig. 8.10B). Another has a fantastic figure of a ram and horns of a bull on human face with trunk and tusks of an elephant and hindquarters of a tiger (Fig. 8.10C). A three-headed beast with head and horns of an antelope joined to the body of a unicorn adorns one seal (Fig. 8.10D), in which one head is in eating posture, another is looking forward, and third is looking backward in (apparent) alarm. Furthermore, there is the 'triskillion', three tigers with bodies crossing each other in the centre (Fig. 8.10E). Finally, one damaged seal shows heads and necks of six animals radiating from a ring-like motif (Fig. 8.10F); of the four unbroken heads, one is of a unicorn, another of a short-horned bull, the third is of an antelope and the fourth of a tiger, the remaining two heads probably represent an elephant and a rhinoceros.

The above picture of the animals of prehistoric India, built up from their actual remains and representations through glyptic art, decorative pottery and figurines, points out to the climatic conditions that might have been prevalent in north-west India, the seat of the Harappan culture that flourished some 4,300 years ago. The present climatic conditions in the Panjab and Sind are hardly suitable for the type of fauna that this tract supported in prehistoric times. The archaeological finds, specially the kiln-dried bricks utilized in building the Mohenjo-daro and Harappa settlements, also indicate the presence of large stretches of highly wooded areas rich in water resources and teeming with a large variety of wild life including the tiger, the elephant, the rhinoceros and the buffalo.

HISTORICAL PERIOD

With the advent of the Aryans and the development of the Vedic literature, prehistory passes into history in India. Animal world, to the Vedic people, was not a separate entity, but a part of the great cosmic

[a] Mackay (2), p. 382.

system embracing the whole world. Biological phenomena, therefore, are not separately treated but, along with other cosmic phenomena, are diffused throughout the Vedic and classical literature. Sifting through this vast mass of literature spread over centuries, a difficult but rewarding exercise, reveals that the ancient Indians were keen observers of the living world, amassing facts of natural history, speculating upon the nature and origin of life, attempting to classify living beings into rational groups based on the modes of reproduction, ways of living or dietary values. Their anatomical, physiological, embryological and genetical observations, however, were chiefly based on their knowledge about man. The only other animals receiving similar treatment were the cattle, horse and elephant, that is, animals of economical or military importance.

ANIMALS AND NATURAL HISTORY

Natural history is probably the most appropriate term to express the observations recorded by the ancient Indians. Though animal names were galore in ancient texts, the science of naming animals had not achieved the status of taxonomy. Animals were observed and named simply for recognition. Several animal names have been based on some structural peculiarities or some distinct traits in habits, making recognition easy. However, these names are not accompanied by any descriptive details which can be taken as an aid to identification. Nevertheless, a good many animals mentioned in the ancient texts have been identified with species known today, because their names have passed on through centuries without any change or as easily reconcilable derivatives and are still in use in different parts of India.

Observations on habits and habitats of several animals have been recorded in the sacerdotal and lyrical works. The impact of Nature on the creative faculties of the poets of olden days has received wide acclaim for their beauty and vividness.

Saṃhitās, Brāhmaṇas and Upaniṣads

The *Saṃhitās*, the *Brāhmaṇas*, the *Āraṇyakas-Upaniṣads* contain several names of animals as well as observations on their habits and habitats. Macdonell and Keith[a] have compiled a list of over 260 animal names used in the Vedic literature. Rao[b] has also dealt with Vedic animals while recording the knowledge of Indian fauna through the ages. The majority of animals listed therein comprise mammals and birds, while reptiles (chiefly serpents), fishes and insects are not numerous. The *Yajurveda* and the *Atharvaveda* are, in particular, full of animal names. The *Yajurveda* provides a list of animal victims in the *aśvamedha* with the horse, as the name of the ritual implies, occupying the place of honour. In the *Atharvaveda*, snakes and worms (*kṛmi*) are mentioned in some details. The

[a] Macdonell and Keith, I and II. [b] Rao (H. S.), pp. 251-80.

Atharvan priest, in giving a series of charms against snake-poison, describes different types of snakes as follows:

> 'O *kairāta*, speckled one, *upatṛṇya* (grass-dweller), brown one listen to me; ye black repulsive reptiles, (listen to me)! . . .'
> 'I release (thee) from the fury of the black serpent, the *taimāta* the brown serpent, . . .'
> 'Both *āligī* and *viligī*, both father and mother, we know your kin everywhere . . .'
> 'The daughter of *urugūlā*, the evil one born with the black—of all those who have run to their hiding-place the poison is devoid of force.'
> 'The prickly porcupine, tripping down from the mountain, did declare this: "whatsoever serpents, living in ditches, are here, their poison is most deficient in force".'[a]

The toxic effects of snake-poison are described with prescription of necessary chants to destroy them. The importance of snakes was obvious and a special science—*sarpavidyā*—formed an important and recognized branch of knowledge from Vedic times.

Sixteen types of *kṛmis*, the obnoxious worms, are mentioned in the *Atharvaveda.*[b] These were regarded as poisonous and spoken of as found in the mountains, forests and in the human body. These were believed to cause diseases of cattle and man. In man, the worms infested the head and ribs and crept into the eyes, nose and teeth. These were described as having dark brown bodies, white in the forepart, with black ears and three heads!

Twenty-eight arthropod names are listed in the Vedic literature, mostly referring to insects, in addition to a few scorpions and spiders. These include ants, bees, cochineal insects, flies, mosquitoes, fireflies and locusts. The depredations caused by the locust to crops were well known, and a few names indicate vermins damaging grains and seeds. Caterpillars and grasshoppers were also distinguished. There is also a reference to crabs.

Of other invertebrates, pearl and conch-shells (Mollusca) are mentioned.

The vertebrates figure pre-eminently in the Vedic literature. Seven fish-names appear in the texts, but it is not certain whether these names refer to individual species or to a group as a whole.

Among the reptiles, snakes, as mentioned earlier, figure prominently, and about 29 names are used to denote various types, some of which are doubtless group-names. Other reptiles include the gharial, chameleon, monitor lizard and tortoise.

Birds and mammals occupy a prominent place in the Vedic literature. Several species of birds, many of them recognizable, have been listed. These include common forms like the sparrow, myna, parakeet, cuckoo,

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[a] *AV.*, V, 13.5–9; Bloomfield's translation.

[b] *AV.*, II, 31.1–5.

pigeon, etc., birds of prey like the vulture, hawk, eagle, owl, aquatic and semi-aquatic forms like the heron, stork, curlew, ducks, geese, swan, and several others.

The mammals known to the Vedic people are of three categories, domestic, semi-domestic and wild. Practically all the species represented in the Harappa culture were known, not surprisingly, because the advent of the Aryans did not make any change in the wild life then extant. The domestic animals were the cow, buffalo, elephant, horse, camel (not very popular), ass, mule, sheep, goat, pig, dog and cat. The jackal and the wolf, and possibly the hyena, skirted the forests around human habitations. The mongoose and the rat were forms common within and around settlements.

Among wild beasts were the carnivores like the lion, tiger, leopard, bear, wolf and hyena. The artiodactyls included the antelope, gazelle, spotted deer, barasingha, sambhar, etc. There is also mention of others, such as the polecat (?), wild boar, monkey, gaur, porcupine, hare and pangolin (?), and the rhinoceros and elephant.

It is rather surprising that the *Ṛgveda* does not mention the tiger, a beast so familiar to the Harappans and so common in the later *saṃhitās*. The most popular carnivores in the *Ṛgveda* are the wolf and the lion. Among the domestic animals, cattle and horse occupy the place of honour; and there are plenty of special terms to distinguish different kinds among these and their calves and foals. In the later stage of the Vedic period, the cow became a very important animal; it was sanctified and its slaughter had been prohibited (except on certain special occasions), a decree that has been so faithfully honoured by the Hindus of all castes even to this day.

The mythology and legends of the Vedic period have been considerably influenced by animals. Many animals, specially the horse and also the kine, goat and deer, figure as the mounts of gods or drawing their luminous cars through the air. The importance of the cow in the Vedic and post-Vedic literature has already been mentioned. In the ritual of sacrifice, the most common practice to appease the galaxy of gods, animals (of several types) figure prominently. The serpent, as a noxious creature, is one of the most conspicuous animals, specially as the foe of Indra, appearing in the form of a demon. Many birds are alluded to as bringing bad omen or good luck.

The ethology of animals did not escape the attention of the Vedic bards. In fact, many animal names take after some peculiar traits either in their structures or in their habits.

The Indian python, frequently referred to in the sacred and mythological lores, is the *ajagar* (the swallower of goats). The Indian koel's habit of depositing its eggs in the nests of other birds is noticed, and the *Vājasaneyī* and the *Maitrāyaṇī Saṃhitās* call this bird *anya-vāpa* which means sowing for others; its other name *parabhṛta* also connotes its parasitic habits. The spiders are called *ūrṇanābha*, meaning wool in the

navel, an appellation no doubt inspired by the way in which the material forming its web comes out of the abdomen.

The cock is *kukkuṭa*, an onomatopoeic word, suggesting the sound emanated by its crowing. Several references are made in the *Ṛgveda* and *Śatapatha Brāhmaṇa* to the casting of slough by serpent. Mention is made in the *Atharvaveda* and *Śatapatha Brāhmaṇa* of peculiar movements of snakes, earning the name of *Datvatī rajju* or 'toothed rope'.[a] Similar lines are also found in the *Aitareya Āraṇyaka*. The poisonous character of snake-bite is frequently mentioned in the *Ṛgveda* and other *saṃhitās*. The *Atharvaveda* mentions the torpidity of snakes in winter when they creep into the earth, a phenomenon now well known as hibernation. The mongoose (*nakula*) has been regarded as the deadly enemy of snakes and immune to their poison by the use of a healing plant, perhaps a blind belief that still persists among our people.

The carnivorous beasts, the lion and the tiger, were dreaded for their dangerousness. The roaring (*nāda*) of the lion is compared to the thunder in the Vedic texts. The king of beasts, as it is called, wanders about (*kucara*) and lives in the hills (*giristha*) and is the terror of other beasts whom he slays. The lion, being dangerous to men, was trapped, ambushed or chased by hunting bands.[b] The tiger, not mentioned in the *Ṛgveda*, finds, however, a frequent mention in the *Atharvaveda* which is taken as an evidence of eastward extension of the Aryan territory during the time when it was said to be composed. The destructive nature of this beast is often alluded to and it passed, like the lion, as a symbol of strength. Man-eating tigers (*puruṣād*) are also mentioned.[c]

The frog is mentioned as the harbinger of rain. The awakening of frogs at the beginning of the rainy season inspired an interesting hymn in the *Ṛgveda*[d] graphically re-enacting a scene with which people in India are very familiar. The chorus of the croaking frogs is compared to the chants of priests exhilarated by *soma* and with the clamour of pupils at school repeating the words of their teacher. The relevant portion of this hymn is quoted below:

> (1) The frogs have lifted up their voice, the voice Parjanya hath inspired.

[a] The figure of speech 'toothed rope', or 'the rope full of teeth', is also used in the *Atharvaveda*. Thus 'on a distant path shall move the biting rope (the serpent)...', *AV.*, IV, 3.2. The *Śatapatha Brāhmaṇa* has it '... for snakes are like rope, and snakes' haunts are like wells (pits)...' (*Śat. Br.*, IV, 4.5.3).

[b] The *Ṛgveda* refers to the lion as follows: 'Exceedingly wise they roar like lions mightily' (*ṚV.*, I, 64.8); 'roar as the lions roar' (*ṚV.*, III, 26.5.7); 'like a dread lion' (*ṚV.*, IV, 16.14); 'as a snared lion leaves the trap that caught him' (*ṚV.*, X, 28.10).

[c] 'The forest animals, the wild animals homed in the woods, the man-eating lions and tigers that roam' (*AV.*, XII, 1.49). Elsewhere, 'Thyself a tiger, dost thou upon this tiger-skin stride (victorious) through the great regions' (*AV.*, IV, 8.4). The tiger's skin was a mark of royalty, as the tiger, and also the lion, was regarded as the king of animals.

[d] *ṚV.*, VII, 103; English translation by Griffiths.

(2) What time on these, as on a dry skin lying in the pool's bed, the floods of heaven descended,
the music of the frogs comes forth in concert like the cows lowing with their calves beside them.

(5) When one of these repeats the other's language, as he who learns the lesson of the teacher,
your every limb seems to be growing larger as ye converse with eloquence on the waters.

(7) As Brāhmaṇs, sitting round the brimful vessel, talk at the soma-rite of Atirātra,
so, frogs, ye gather round the pool to honour this day of all the year, the first of rain-time.

Post-Vedic literature follows the tradition of the Vedas in recording the names of animals and some observations on their natural history. As food and as offerings for sacrifice, animal life had acquired an important status. The sport of hunting which is one of the time-honoured recreations and means for obtaining protein food must have assisted in amassing observations which gradually accumulated and served as a storehouse of knowledge that stimulated thought and developed concepts about classification, heredity, embryology, etc.

Animals in the Epics

Constant references are made to animals in the two great epics, the *Rāmāyaṇa* and the *Mahābhārata*.

Chaudhuri and Roy have provided lists of animals, both aquatic and terrestrial, as extant in the *Rāmāyaṇa*. They include the commonly known mammals, birds, fishes, insects, etc. The aquatic animals are the mythological *makara* (whose identity is still in dispute), *nakra* (crocodile, gharial) and *timi* (whale). The insects are *indragopa* (cochineal), *kośakāra* (silk-worm), *daṃśa* (gnat), *maśaka* (mosquito) and *ṣaṭcaraṇa* which literally means six feet and can be applied to any insect. The scorpion (*vṛścika*) is also referred to. Fishes have been identified by Hora (1952) as *Garra mullya* (*cakratuṇḍa*), *Mastacembalus armatus* (*nalamīna*), *Labeo fimbriatus* (*rohita*), *Channa striatus* (*śakula*) and *Wallago attu* (*pāṭhīna*). There are a few names signifying snakes. Birds include the *kāraṇḍava* (coot), *kurara* (osprey), *krauñca* (pond heron), *cakravāka* (brahminy duck), *koyaṣṭibhas* (lapwing), *kadamba* (purple moorhen), *kaṅka* (gray heron), *gṛdhra* (vulture), *śikhin* (peacock), *śyena* (hawk or falcon), *dātyūha* (water-fowl), *madgu* (aquatic bird, probably cormorant) and *sārika* (a bird of doubtful identity).

The most familiar animal in the *Rāmāyaṇa* is indeed the *kapi* or monkey. There was a varied assortment of these creatures variously called *golāṅgula*, *gopucchas* (probably synonymous with the Indian langur), *vānara* (similar to man and living in forests), *plavaga* or *plavaṃga* (moving by leaps, a familiar habit of monkeys when running). The monkey was also known

as *śākhāmṛga* (an animal living in the branches of trees, obviously referring to its arboreal habits). Eleven types of deer are listed in the *Rāmāyaṇa*, some of which are no doubt our common species.

The *Mahābhārata* is full of references to a large variety of animals, many of which are common to *Rāmāyaṇa* and the Vedic literature. Of great interest in this epic is the *Āstikaparva*, which deals with the *nāgayajña* of Janmejaya, a descendant of the Pāṇḍavas. Janmejaya, to avenge the death of his grandfather Parikṣit who was the fatal victim of snake-bite, organized a big snake-hunt to decimate the serpent tribe on the earth. In connection with this anti-snake ritual, about 170 species of snakes are listed. Vedi has compiled a list of snakes mentioned in Indian literature. This list enumerates 418 names, of which many are no doubt synonyms.

The *Mahābhārata* has interesting explanations for the poisonous nature of some snakes and their forked tongues (*dvijihva*). Some snakes are poisonous because they licked drops of the *halāhala*, deadly poison retrieved along with *amṛta* from the primordial sea when it was churned by the gods and demons.

Similarly, the forked tongue of snakes has a mythological explanation. The much sought-after vessel of *amṛta* was kept on a bed of sharp-edged grass (*kuśa*) under strong guard. The snakes sneaked near the repository, crawling unnoticed; their darting tongues were said to be split into two by the sharp blades of *kuśa*.

Animals in the Medical and Miscellaneous Works

The two great medical works, the *saṃhitās* of Caraka and Suśruta, give an almost complete list of animals of various groups known till then as also some details about anatomy, zoological classification, ecology and dietary value of animals, and physiology of man. The treatment followed is basically similar in the two treatises. While Caraka gives some details about parasites, Suśruta's spectrum is much wider, embracing leeches, insects, spiders, scorpions, frogs, fishes, reptiles (specially snakes), birds and mammals.

Suśruta's account of fishes inhabiting various freshwater habitats reveals a keen insight into the correlation between the form and locomotion of fishes, as Hora[a] has pointed out. The rudiments of the science of functional morphology, that is correlation between forms and functions, are clearly discernible is Suśruta's compendium.

Ray and Gupta have given an interesting scientific synopsis of the *Caraka Saṃhitā* with references to Caraka's zoology. For Suśruta, the excellent English translation of the *Suśruta Saṃhitā* in three volumes by Kunja Lal Bhishagratna,[b] as also Seal's work, are recommended.

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[a] Hora (1), pp. 1–7.

[b] 'Bhishagratna' is the Ayurvedic title conferred on the author Kunja Lal Bhaduri. On the title-pages of the volumes the prefix 'Kavirāj'—a title equivalent to 'Doctor' as is usually ascribed to medical practitioners—has been used for the author's name. 'Sharma', used as surname by the author on the dedication page of Vol. 1, is often used by the Brahmans.

Reverting to early natural history one cannot but be impressed by allegorical tales, narrated in the *Jātakas*, dealing with animals. Hora,[a] and Hora and Saraswati[b] have given primarily an account of fish in the *Jātaka* tales and sculptures (Fig. 8.11), but have also casually mentioned other animals, elephants, monkeys, antelopes, crabs, crocodiles (?), sharks (?), etc., occurring in the tales and associated sculptures at Bharhut (200 B.C.)



FIG. 8.11. Animals in *Jātaka* sculptures (after Hora, 1955).

and Sanchi (100 B.C.). The animals mentioned in the inscriptions on rock and pillar edicts of Aśoka have been given by Chakravarti[c] and Hora.[d] Jayaram has given an account of the knowledge regarding animal life in India during the early Jaina and Buddhist period. An important development

[a] Hora (5), pp. 1–13.

[b] Hora and Saraswati, pp. 15–30.

[c] Chakravarti (M.), pp. 361–74.

[d] Hora (2 ii), pp. 43–56.

during this period was the propagation of the creed of *ahiṃsā*, a reaction against the sacrificial ritual of the Vedic Hindus. Though there is no substantial addition to the list of animal names which had already gained currency during the period prior to this, there is a distinct change in the outlook towards animals. It was decreed that animals should not be needlessly slaughtered, though there was no ban on eating meat. For the first time we hear about national parks (*abhayāraṇya*), where animals could move about unmolested. In Kauṭilya's *Arthaśāstra*, there are indications of regulations governing fisheries, livestock, hunting, etc.

The period preceding the Christian era and a few centuries immediately after, witnessed intense philosophical-scientific activities, no doubt activated by the Buddhist and Jainist reaction towards orthodox Brahminism (in centuries preceding the birth of Christ) and Hindu reaction against Buddhism in the following half millennium after the Gregorian Calendar was introduced. This was the period of Hindu Renaissance, which crystallized the different systems of philosophy and produced commendable works on mathematics, astronomy, chemistry, physics, botany and zoology.

In the post-Christian period, specially in the later half of the first millennium A.D., some remarkable works on Sanskrit poetry were produced. Among these the lyrics and dramas of Kālidāsa have received world-wide acclamation for the poet's deep understanding of Nature. As Macdonell, while discussing the works of that great poet Kālidāsa, aptly remarks about *Ṛtusaṃhāra*: 'Perhaps no other work of Kālidāsa's manifests so strikingly the poet's deep sympathy with Nature, his keen powers of observations, his skill in depicting the Indian landscape in vivid colours.'[a] This is true indeed not only of Kālidāsa but also of many other Sanskrit poets and dramatists.

Animals and plants figure prominently in Kālidāsa's poetry, details about which can be seen in Law's book[b] on the birds of Kālidāsa, and in various articles by Gupta[c] dealing with birds and insects mentioned by the poet. His understanding of animal life can be easily gauged by an account of summer in *Ṛtusaṃhāra*, in which the effects of heat on animal life are vividly portrayed by the thirst or lethargy that it produces in serpent, lion, elephant, buffalo, boar, gazelle, peacock, crane, frog and fish; and the devastation caused by forest fire is graphically described as the tongues of flame devour trees and shrubs and drive before them crowds of terror-stricken beasts.

Varāhamihira, the great encyclopaedist, did not fail to mention nature and animals in his *Bṛhatsaṃhitā*, in which he has extensively described the cow, dog, cock, tortoise, goat, horse and elephant in separate sections.

The *Amarakośa*, a great lexicographic work by Amar Singha, gives meanings, synonyms and definitions (at places) of practically all animal names in the Vedic and post-Vedic texts. For a list of animal names current during and before this great lexicon (as important as Pāṇini's grammar), one can unhesitatingly refer to this work. Though not zoological by any means, the animals have been listed according to their habitats as well as habits.

[a] Macdonell, p. 337. [b] Law (S. C.). [c] Gupta, pp. 145–72.

Classification of Animals

The *Ṛgveda* does not furnish any indication of classification of animals other than the division of common mammals into two groups, viz. the domestic forms (*grāmya*) and those living in forests (*āraṇya*), the wild animals. Later in the *Atharvaveda* we come across the term *jagat*, moving or mobile, to encompass the domestic forms vis-à-vis *śvāpada* which include the wild ones. Among the domestic forms, the solid-hoofed (*ekaśapha*) horse, ass and mule and the split-hoofed (*dviśapha*) were further distinguished from one another by the presence of incisors in both the jaws (*ubhayadanta*: in the *Ṛgveda* and later *saṃhitās*) and by having incisors in the lower jaw only (*anyatodanta*) as in the cattle and sheep. Man has been included among the *ubhayadanta*, that is with incisors in both the jaws, in a passage in the *Taittirīya Saṃhitā*. Man as *dvipada* (biped) was further distinguished from the *catuṣpada* (quadruped) animals. Mammals were called *paśu* (also *mṛga* later on), birds (*pakṣī* having wings) and reptiles (and perhaps other crawling animals) were *sarīsṛpa* (the crawlers); snakes were *sarpa*, and insects (and probably their larvae) were *kīṭa* (non-flying) and *pataṅga* (winged insects). In the *Atharvaveda*, as we have already seen, obnoxious parasites of man and cattle were called *kṛmi*; possibly all (or at least some) of the kinds named were worms parasitizing man and domestic animals.

The first attempt to classify animals in a rational (though not natural) way is found in the *Chāndogya Upaniṣad*, where they are divided into three groups according to the nature of their *bīja*, literally meaning seed, but metaphorically implying mode of origin and development. These three groups of animals are *aṇḍaja* (born from egg), *jīvaja* (born alive or born from womb) and *udbhijja* (born from sprouts). The *Aitareya Āraṇyaka* adds one more group, *svedaja* (born out of sweat), generated by hot moisture to comprise flies, worms, etc., which becomes *jarāyuja* in later works. Further, the term *jīvaja* of the *Chāndogya* is replaced by *jaruja*. The term *jarāyu*, used in *Atharvaveda* in the sense of 'serpent's skin', is more frequently used in the later Vedic texts to denote the outer covering (chorion) of the embryo as opposed to ulva, the inner covering or amnion (*Ṛgveda*, *Vājasaneyī Saṃhitā*, *Aitareya Brāhmaṇa*, *Śatapatha Brāhmaṇa*, etc.). The *jaruja* or *jarāyuja*, therefore, comprises placental mammals.

The *Manu Smṛti* divides the living world into *sthāvara* (fixed or immobile plants) and *jaṅgama* (the mobile animal world). The animals are further classified into three groups, namely (i) *jarāyuja* which includes *paśu* (domestic quadrupeds), *mṛga* (wild herbivores), *vyāla* (wild carnivores), *ubhayatodanta* (with incisors on both jaws), *rākṣasa*, *piśāca* and man; (ii) *aṇḍaja* which includes birds, snakes, crocodiles, fishes, tortoises and turtles and similar kinds of terrestrial (*sthalaja*) and aquatic (*audaka*) animals; and (iii) *svedaja* which comprises organisms born out of heat and moisture of the earth, viz. stinging gnats and mosquitoes (*daṃśa* and *maśaka*), lice (*yūka*), flies, bugs and others.

The class *udbhijja* comprises the fixed plant world. Terms such as *pratuda* and *viṣkira* came to be used later by Caraka and Suśruta for birds, the former to indicate those which tear their food with their beaks and the latter for those which scatter their food with claws. There is also the use of the term *pañcanakha* (five-clawed) which includes *śvāvit* (? pangolin), *śallaka* (porcupine), *godhā* (monitor lizard), *khaḍga* (rhinoceros), *kūrma* (tortoise) and *śaśa* (hare).

The division of the animal world into four groups according to their modes of birth, first made in the Vedic literature, gained wide currency in the post-Vedic literature and found frequent mention in the *Purāṇas* and the *Mahābhārata*. Caraka and Suśruta both followed this classification in their medical treatises.

According to Caraka[a] the *jarāyuja* (placental animals) includes man, the quadrupeds, etc.; the *aṇḍaja* (egg-born or oviparous) fishes, reptiles and birds; the *svedaja* (born of moisture and heat, i.e. spontaneously or asexually reproduced) worms, mosquitoes, etc.; and all animals, born of vegetable organisms, are included in the class *udbhijja*. He further mentions that each *yoni* has innumerable divisions and consequently the appearance, etc., of organisms are also exceedingly varied.

Pāṇini defines *kṣudra jantu* as small organisms or animals without bones (*anasthi*) or animals so small that hundreds or even thousands of them can be held in the palm of a hand or animals up to the size of the mongoose.[b] Patañjali further elaborates the definition of small animals (*kṣudra jantu*) as follows: 'What are *kṣudra jantu*? Boneless are *kṣudra jantu*. Or those that number more than a thousand in a palmful are *kṣudra jantu*. Or those that cannot be easily crushed are *kṣudra jantu*. Or animals up to ichneumon (*nakula*) are *kṣudra jantu*.'

The definitions of small (or minute) organisms given by Pāṇini and Patañjali are, however, defective, since these include boneless and bloodless (red blood) creatures up to the size of the mongoose (ichneumon), the latter having both bones and blood. Obviously, these are an assemblage of small organisms from very minute to those up to the size of ichneumon.

Praśastapāda, the well-known Vaiśeṣika philosopher, divides animals into two great divisions: *ayonija* or animals that are asexually reproduced and are of small dimensions (*kṣudra jantu*) of Pāṇini and Patañjali, and *yonija* or sexually reproduced from the union of male and female germ elements. The *yonija* are further subdivided into *jarāyuja* (man, domestic and wild quadrupeds), or viviparous, and *aṇḍaja*, the oviparous animals like birds and *sarīsṛpa* (reptiles, etc.).

In Praśastapāda's own words:

> *tatra śarīraṃ dvividhaṃ yonijamayonijaṃ ca | tatrayonijamanapekṣaśukraśoṇitam . . . | śukraśoṇitasannipātajaṃ yonijaṃ tattu dvividhaṃ jarāyujamaṇḍajaṃ ca | mānuṣapaśumṛgāṇāṃ jarāyujaṃ pakṣisarīsṛpāṇāmaṇḍajaṃ |* [c]

[a] *CS. Śā.*, 3.16. [b] *MBhā.*, 2.4.1. [c] *PBh. dravya, pṛthivīnirūpaṇaṃ.*

He thus modifies the Vedic classification of animals, retaining the *aṇḍaja* and *jarāyuja* and including them in the *yonija* division (organisms formed out of the union of semen and menstrual blood), while including small animals into *ayonija* or asexually reproduced forms. The *svedaja* and *udbhijja* are not, however, mentioned, because probably the division *ayonija* was developed to include these. Udayana has defined the term *jarāyu* as placenta; and the *sarīsṛpa*, according to the same author, includes insects, fishes, reptiles and snakes.

Suśruta divides animals into four groups, e.g. *saṃsvedaja* or *svedaja*, *jarāyuja*, *aṇḍaja* and *udbhijja*. In various texts the order of enumeration is, however, different. Ḍallaṇa, the commentator of Suśruta, defines the *svedaja* as organisms born out of moisture and heat, which are essential in generating all forms of animal life.

Among the examples of the four groupings are mentioned *vyāla* (carnivorous quadrupeds) and *paśu* (herbivores) as *jarāyuja*; birds, snakes and *sarīsṛpas* among *aṇḍaja*; *kṛmi*, *kīṭa* and *pipīlikā* (worms, insects, ants, etc.) among *svedaja*; frogs and cochineal insect as typifying those that burst forth from the ground, the *udbhijja*.[a] Ḍallaṇa further thinks that these divisions are really cross-divisions. He mentions that bats and *valākās* among birds are viviparous (some *valākās* are oviparous, some are viviparous). Similarly, among the *aṇḍaja* snakes, *ahipatākā* (a kind of non-venomous snake) is viviparous.[b] The same is true of some species of ants which lay eggs or burst forth from the ground in the *udbhijja* way.

The *sarīsṛpas* together with the birds and snakes are included among the oviparous or *aṇḍaja* animals by Suśruta, which contain, in the opinion of Ḍallaṇa, fishes and *makara* (sea-monsters with fierce teeth = ? sharks) and also tortoises and crocodiles.

The same commentator explains that the *svedaja* organisms are produced due to the moisture and heat either of the earth or of the organisms. Among these the worms (*kṛmi*) arise from the moisture of the faeces in the bowels or from putrefying dead bodies, as Guṇaratna notes in *Tarka-rahasya-dīpikā*. They may also arise from decomposing milk or curd.

The moisture-born *kīṭa* includes scorpions and the six-spotted venomous insect *ṣaḍvindu*. According to Patañjali (also Suśruta in *Kalpa-sthāna*, Ch. VII) scorpions arise from cow-dung, excreta of snakes and rotten wood.

The *pipīlikā*, that is, ants and the like insects, as Ḍallaṇa comments, have a triple mode of birth; they are born from moisture and heat (*svedaja*), from eggs (*aṇḍaja*) and sometimes burst forth from the ground (*udbhijja*).

Śaṅkara (*Chāndogya Upaniṣad*, *Prapāṭhaka* 6, part 3) commenting upon the classification of animals, divides them into three groups only,

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[a] Seal, p. 179.

[b] Although all snakes are oviparous, in some (Viperidae and some other species of colubrids) the eggs continue development inside the 'uterus' and the young ones are born alive. These are examples of ovo-vivipary. Perhaps Ḍallaṇa observed such cases when noting that *ahipatākā* is viviparous.

jīvaja (viviparous), *aṇḍaja* and *udbhijja*. Śaṅkara, like Caraka, agrees that *udbhijja* animals arise from vegetable organisms, but he also holds the view that *svedaja* animals must be included partly under *aṇḍaja* and partly under *udbhijja*.

Seal[a] thinks that Śaṅkara's explanation takes it that, though vegetable organisms may pass off into animal, inorganic matter without *bīja* (seed or ovum) cannot give rise to animal life or, in other words, life cannot arise *de novo*, the elementary fact that every student of biology has to learn in school. Patañjali, however, believes that not only animal organisms but also vegetable organisms, e.g. grasses, can grow from inorganic matter. The *dūrvā* grass is cited as an example; it can grow from deposits of hair of goats and cows, just as scorpions are seen to develop from cow-dung. Patañjali explains that these are not cases of growth but merely of unfolding (transformation).

A different system of classification of animals has been devised by Umāsvātī in the ancient Jaina work, *Tattvārthādhigamasūtra*. Here, the number of senses possessed by an organism is taken into account, and the animal is placed in an ascending series according to this number.

1. Those animals which possess two senses—touch and taste:[b]

   (i) *Apādika*—worms without appendages.
   (ii) *Nūpuraka*—ring-like with pendants—Annelida.
   (iii) *Gaṇḍūpada*—knotty-legged animals—Arthropoda (including Crustacea and Myriapoda).
   (iv) Some kinds of molluscs, such as *śaṅkha* (conch), *śuktika* (pearl oyster) and *śambuka* (spiral shell, many snails).
   (v) *Jalūkā*—leeches (Hirudinea).

2. Animals possessing three senses, viz. touch, taste and smell:[c]

   (i) *Pipīlikā*—ants.
   (ii) *Rohiṇikā*—red ants.
   (iii) *Upacikā, kunthu, tuburuka*—bugs and fleas.
   (iv) *Trapusabīja* and *karpāsāsthikā*—cucumber- and cotton-weevils; lice.
   (v) *Śatapadī* and *utpataka*—centipede and springtail.
   (vi) *Tṛṇapatra*—plant-lice.
   (vii) *Kāṣṭhahāraka*—wood-destroyers, e.g. termites or white ants.

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[a] Seal, p. 180.

[b] *tad yathā kṛmyādinām apādika—nūpuraka—gaṇḍūpada—śaṅkha—śuktikā śambukā—jalūkā—prabhṛtīnāṃ . . . sparśanarasanendriye bhavataḥ* |

—*TSū. Bh.*, II, 24.

[c] *pipīlikā—rohiṇikā—upacikā—kunthu—tuburuka—trapusabīja—karpāsāsthikā—śatapad-yutpataka—tṛṇapatra—kāṣṭhahāraka—prabhṛtīnāṃ trīṇi sparśanarasanaghrāṇāni* |

—*TSū. Bh.*, II, 24.

3. Animals with the senses of touch, taste, smell and sight:[a]

   (i) *Bhramara*, *varaṭa* and *sāraṅga*—bees, wasps and hornets.
   (ii) *Makṣikā*, *puttikā*, *daṃśa* and *maśaka*—dipterous flies, gnats, mosquitoes.
   (iii) *Vṛścika* and *nandyāvarta*—scorpions and spiders.
   (iv) *Kīṭa-pataṅga*—flying and non-flying insects.

4. Animals (man and the *tiryakyonis*) with five well-developed and active senses:[b]

   (i) *Matsya*—fishes (Pisces).
   (ii) *Uraga*—limbless reptiles including snakes.
   (iii) *Bhujaṅga*—limbed reptiles and (?) amphibians.
   (iv) *Pakṣī*—birds (Aves).
   (v) *Catuṣpada*—quadrupeds (Mammalia).

The first three divisions as stated above come under the invertebrates and include *svedaja* and *udbhijja* of the earlier classifications and the fourth includes only vertebrates.

The fourth is further subdivided into the oviparous and viviparous groups:

(*a*) *Aṇḍaja*—fishes and reptiles, including *sarpa* (snakes), *godhā* (monitor lizard), *kṛkalāsa* (chameleons and garden lizards), *gṛhagolika* (wall-lizards); *matsya* (fishes), *kūrma* (tortoise), *nakra* (crocodiles), *śiśumāra* (dolphins and porpoises) and *lomapakṣa pakṣi* (birds with feathered wings).[c]

Two flaws in this otherwise good classification can be noticed. One is the inclusion of dolphins among *aṇḍaja* (perhaps their fish-like features and behaviour caused this mistake) and the omission of frogs because they were traditionally believed to be *udbhijja*, that is, bursting forth from the ground.

(*b*) *Jarāyuja*—placental mammals. Here *jarāyuja* is restricted to mean those mammals that have non-deciduate placenta, e.g. man, cow, buffalo, goat and sheep, horse, ass, camel, deer, yak (*chāmara*), hog, *gavaya* (mithun), lion, tiger, bear, panther, dog, jackal, cat, etc.[d]

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[a] *bhramara—varaṭa—sāraṅga—makṣikā—puttikā—daṃśa—maśaka—vṛścika—nandyāvarta—kīṭa-pataṅgādināṃ catvāri sparśanarasanaghrāṇa—cakṣūṃṣi* |
—*TSū. Bh.*, II, 24.

[b] *śeṣānāṃ ca tiryagyonijānāṃ matsyoragabhujaṅgapakṣi—catuṣpadānāṃ sarveṣāṃ ca nārakamanuṣyadevānāṃ pañcendriyāni* |
—*TSū. Bh.*, II, 24.

[c] *aṇḍajānāṃ sarpa—godhā—kṛkalāsa—gṛhagolika—matsya—kūrma— nakra—śiśumārādīnāṃ* |
—*TSū. Bh.*, II, 34.

[d] *Jarāyujānāṃ manuṣya—go-mahiṣājāvikāśca—kharoṣṭra—mṛga—camara—varāha—gavaya—siṃha—vyāghrarkṣa—dvīpiśva—śṛgāla—mārjārādināṃ* |
—*TSū. Bh.*, II, 34.

(c) *Potaja*—mammals with deciduate placenta which is thrown off as an afterbirth, such as *śallaka* (porcupine), *hasti* (elephant), *śvāvit* and *lāpaka* (hedgehog and other insectivores), *śaśa* and *śāyikā* (hares and squirrels), *nakula* (mongoose), *mūṣika* (rats and mice), and *carmapakṣa pakṣī* (birds with leathery wings), that is, bats including *valguli* (flying fox), *pakṣivirāla* (Microchiroptera) and *jalūka* (apparently meaning blood-sucking bats or vampires).[a]

Umāsvātī's classification, whatever might be its defects from the modern point of view, was distinctly a bold advance and excelled contemporary efforts made in the western world dominated by Aristotle's ideas and contributions. In fact, in their attempts to introduce systems of classification, the ancient Indians appear to have made much more serious efforts to bring together known animals within the bounds of certain rational groups and achieved a larger measure of success than did Aristotle.

In addition to the classification of animals on the basis of their modes of reproduction or possession of a series of senses, Caraka and Suśruta classified animals according to their dietary habits and habitats. Though the two systems agree in broad outlines, there are some differences in details worthy of notice.

Caraka's classification is as follows:

(1) *Prasaha*—carnivorous and non-carnivorous animals and birds that fall on their food with force.

(2) *Anūpa*—animals that live in marshy or water-logged areas or graze on river banks.

(3) *Bhūśaya* or *vileśaya*—subterranean or cave-dwelling animals.

(4) *Vāriśaya*—marine and freshwater animals.

(5) *Jalacara*—amphibious animals.

(6) *Jāṅgala*—mostly species of deer that live in dry and hilly forested lands.

(7) *Viṣkira*—birds that scatter their food in picking.

(8) *Pratuda*—birds that pierce or tear their food (worms or fruits) with beak.

Suśruta's classification begins with two divisions which are further subdivided into 13 groups distinguished by natural differences in food and habitat. The first two divisions are: (1) *jāṅgala* or animals that live on dry hilly country or jungles and (2) *anūpa*, comprising animals that live in marshy or water-logged lands (or in water).

The 13 classes within these two divisions are:

(1) *Jāṅgala* animals: *jaṅghāla*, *viṣkira*, *pratuda*, *guhāśaya*, *prasaha*, *parṇamṛga*, *vileśaya* and *grāmya*.

(2) *Anūpa* animals: *kulecara*, *plava*, *kośastha*, *pādina* and *matsya*.

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[a] *potajānāṃ śallaka—hasti—śvāvillāpaka—śaśa—śāyrikā—nakulamūṣikādīnāṃ carmapakṣiṇāṃ ca pakṣāṇāṃ jalūkā—valgulī—bhāraṇḍa—pakṣivirālādināṃ garbhojanma* |
—*TSū. Bh.*, II, 34.

The land animals (*jāṅgala*) have three groups exclusively made up of birds. These comprise *prasaha* including birds of prey, like vultures, kites, owls, etc., *viṣkira* meaning birds that scatter their food while picking up, and *pratuda*, that is, birds that pierce and tear their food. Except that Caraka's *prasaha* includes birds as well as mammals, the other two groups are similar. The remaining five groups of *jāṅgala* animals, with the exception of several kinds of reptiles included under *vileśaya* and a few under *parṇamṛga*, contain mammals.

The *parṇamṛga*, creatures that live in the trees (arboreal animals), are apes, monkeys, squirrels, and some reptiles and carnivores. The *jaṅghālas* are wild deer and antelopes, strong-legged and quick-footed, that run about on dry land. The *grāmya*, living in villages, comprises the horse, mule, ass, camel, goat, sheep, cow, etc. They are herbivorous quadrupeds, some of which are *ekaśapha* or solid-hoofed.

The carnivorous beasts like the lion, tiger, wolf, hyena, bear, panther, cat, jackal, *mṛgervāru*, etc., comprise *guhāśaya* that live in natural caves or hollows. The wolf (*vṛka*) is defined as a dog-like animal, smaller in size than the lion and tiger.

The animals leading subterranean life in burrows and holes, and therefore called *vileśaya*, include rodents, insectivores and reptiles.

The *anūpa* group has a mixed assortment of vertebrates and invertebrates. The *kulecara* comprises herbivorous quadrupeds, like the elephant, rhinoceros, *gavaya* (mithun), buffalo and various kinds of deer, that frequent the banks of rivers and ponds. The *plavas* are aquatic birds like ducks, geese and cranes. Of the remaining three groups, the *matsyas* are fishes divided into two groups, marine and freshwater, *timi* and *timiṅgila* and *makara* (whales and sharks?) finding place among marine fishes. Forms of body and peculiarities of locomotion of freshwater fishes from different types of habitats have been described with a certain degree of accuracy.

The *kośastha* of the *anūpa* comprises various kinds of molluscs living in shells. The *pādīna* includes a mixed assemblage of animals having pedal, or fin-like appendages, and to this group belong the oval- or oblong-shaped tortoises and turtles (*kūrma*), crocodiles (*kumbhīra*), white and black crabs (*karkaṭa*) and the *śiśumāra*, apparently the dolphin, with a muscular body, sharp protruding snout, breathing with a blow-hole out of water.

In addition to the dietary classification, both Caraka and Suśruta deal with groups of obnoxious and poisonous animals. Caraka's *kṛmi-varga* dealing with worms or parasites contains four divisions depending on the location of the vermins, e.g. (*a*) those living in the body excretions—*yūka* (lice), *pipīlikā* (ants); (*b*) those living in the blood (blood-parasites)—*audumbara, jantumātā, keśada, lomada, lomadvīpa, saurasa*; (*c*) those living in the mucus and phlegm—*antrada, curu, darbhapuṣpa, hṛdayada, mahāguda, saugandhika, udaraveṣṭa*; (*d*) those living in the faeces—*kakeruka, leliha, makeruka, saśālaka, sausurūda*.[a]

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[a] Ray and Gupta, pp. 35–36.

Except for the first two, it is not possible to identify the others by names only. It should, however, be acknowledged that Caraka ascribed certain diseases of men to parasites living inside various parts of the body.

The creatures with poisonous fangs listed by Caraka under the *gomāyu-varga* include the rats, snakes (*āśīviṣa*), leeches, wall-lizards, spiders, scorpions, frogs, fishes, mongooses, flying insects, centipedes, hornets, tigers, lions, dogs and hyenas. Nine kinds of snakes, of which a few are apparently poisonous, are also listed.

Suśruta has listed 20 kinds of worms (*kṛmi*) or parasites of men, originating in faeces (*purīṣaja*), cough or phlegm (*kaphaja*) or in blood (*raktaja*). Excepting for two or three, all the other names of parasites are different from those of Caraka.

The noxious animals whose poisons are dangerous to man are listed by Suśruta in some detail. The seat of poison of celestial serpents lies in their breath, of terrestrial ones in their fangs, and of cats, dogs, monkeys, *makaras*, frogs, *pāka-matsyas*, monitor lizards (*godhā*), molluscs (snails), *pracalakas* (a kind of insect), geckos and many insects in their teeth and claws.

Among the noxious forms are listed 18 types of rats, 67 'families' of insects and 30 kinds of scorpions. The scorpions are classified into *manda-viṣa* or mild-poisoned (12 kinds) germinating from cow-dung or any other rotten substances, *madhyaviṣa* or medium-poisoned (3 kinds) and strongly poisoned or *tīkṣṇaviṣa* (15 types) which germinate from the putrefied dead body of a snake or any poisoned animal. Their characters and effects of venom are also described. Spiders are classed into fatal (non-curable) and non-fatal (curable) types depending on the nature of their poison. Of the 16 kinds of spiders listed, eight are fatally poisonous and the other eight are mildly poisonous. Centipedes are divided into eight kinds, and among insects, following centipedes, are listed eight different kinds of frogs that are said to be venomous.

Snakes are treated by Suśruta in great detail. Five different 'families' are noted, of which one is non-venomous and four (including a hybrid group) are venomous. The venomous group includes *dārvikara*, the cobras of 26 varieties, hooded serpents, swift in their movements and with marks of chariot-wheels, ploughs, umbrellas, etc., on their hood. *Maṇḍali*,[a] another group of venomous serpents containing two species, are thick, slow-moving, nocturnal and bear circles or rings on their bodies. They do not have hoods. *Rājimat*,[b] the third group of venomous serpents, contains ten forms, non-hooded and nocturnal in their habits, bears series of dots or marks, often of variegated colours, on the upper parts and sides.

[a] The description of *maṇḍali* (vipers) given by Suśruta is fairly accurate. He lists two species of vipers, and this is in agreement with the current knowledge about Indian snakes. Only two species of vipers, *Vipera russelli* and *Echis carinatus*, are known in India, and the description given by Suśruta tallies fairly well with that of *V. russelli*—the Russell's viper.

[b] This corresponds fairly well with coral snakes.

Twelve non-venomous species and ten of hybrids (*vaikarañja*) are listed. *Ajagara*, the Indian python (*Python molurus*), is mentioned as non-poisonous.

Suśruta has also extensively dealt with the leeches (*jalaukā*) which were utilized in sucking out vitiated blood from the body. *Jalaukā*, creatures whose lives depend on water, are divided into 12 'species', of which six are venomous and six non-venomous. Characters of different 'species' are described in some detail, which include the colouration, size, girth, distinctive spots, etc., on the body. The natural habitats of the leeches and their geographic distribution are also given. Venomous leeches are said to originate in the decomposed urine and faecal matter of toads and venomous fishes in pools of stagnant and turbid waters. The origin of non-venomous forms is ascribed to such decomposed matter as the putrefied stems of several aquatic plants and the common zoophytes that live in clear water.

The value of accurate identification of animals and plants was not unknown to the ancient Indians. The nomenclature adopted by them, generally derived from some characteristics of the organism or from their habits or habitats, is an adequate testimony to their efforts in this direction. Apparently, because of their constant familiarity with nature and life around them, they relied almost exclusively on names for identification of living objects and have left little descriptive accounts. For example, Varāhamihira, according to B. K. Sarkar,[a] emphasized the importance of names in different countries; and hence the animals first be identified by their names! He also attempted to classify animals according to their habits into nocturnal and diurnal kinds and into those that are seen during both day and night.

References available in ancient texts indicate that the Indian philosophers and scholars of antiquity were also systematists and did try to identify animals and plants more or less along lines now characteristic of modern taxonomists. Seal[b] quotes from some (unnamed) handbooks the precise descriptions of deer and birds given by Ḍallaṇa, the commentator of Suśruta. He further cites the authority of Ḍallaṇa who has referred to the classification of *kīṭas* (insects and reptiles) by Lādyāyaṇa, a noted specialist on the group. Lādyāyaṇa gave criteria for distinguishing various types of *kīṭas* by structural and behavioural peculiarities like '(1) dottings or markings, (2) wings, (3) pedal appendages, (4) mouth, with antennae or nippers (*mukhasandaṃśa*—Ḍallaṇa), (5) claws, (6) sharp-pointed hair or filaments, (7) stings in the tail, (8) hymenopterous character (*saṃśliṣṭaiḥ pakṣaromabhiḥ*), (9) humming or other noise, (10) size, (11) structure of the body, (12) sexual organs . . . and (13) poison and its action on bodies.'[c]

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[a] Sarkar (B. K.), pp. 208–96.
[b] Seal, p. 197.
[c] Seal, p. 200.

Last but not the least, we should like to refer to Ghosal's elaborate treatment, in his own way, of classification of animals in ancient Hindu literature.[a]

ANATOMY AND PHYSIOLOGY

Ghosal states that the growth of knowledge of anatomy in ancient times took place chiefly from the necessity of treatment of human beings and domestic animals, and was based on the animals sacrificed in *yajña*. He further states that there are evidences of development of the knowledge of comparative anatomy in the ancient literature. The data compiled by him, though valuable as an indicator of the interest in animal and plant life, throw little light on the knowledge about anatomy that the ancient Indians actually possessed. He has, however, cited numerous ancient references (mostly in manuscript form) dealing with the veterinary sciences, specially those referring to elephants and horses, which were of importance to the kings and emperors in hunting and warfares. The treatises on veterinary medicine, the *Gajāyurveda* and *Aśvāyurveda*, have chapters on the anatomy and physiology of elephants and horses, but besides enumerating various parts of animal bodies along the lines given in the *saṃhitās* of Caraka and Suśruta, there is nothing descriptive of note.

EMBRYOLOGY

As in anatomy and physiology, embryological knowledge of the ancient Indians was exclusively the product of observations made on human beings.

The semen, according to Suśruta, is the final product of metabolic activity of the body. Conception has been considered to be due to the union of sperm and ovum. The various signs of pregnancy, and preparation necessary for a full-term pregnancy, along with the developmental stages of the foetus, beginning from the conception to the delivery, have been fairly accurately described in the Vedic and later Indian literature. The *Garbhopaniṣad* is one of the earliest works to record the development of human foetus. A more detailed account of the early development is given by Suśruta. Keswani[b] has summarized the information contained in these two works.

HEREDITY AND SEX-DETERMINATION

The question of transmission of hereditary characters occupied the thoughts of the ancient Hindus since the Vedic times. In the *Brāhmaṇas* the question is first asked how specific characters are transmitted from the

[a] Ghosal's *Hindu Prāṇivijñān*, written in Bengali, presents a comparative study of the history and development of zoology in India and Europe and is a comprehensive source-book on early Indian zoology.

[b] Keswani, pp. 206–25.

parent to the offspring. The offspring belongs to the same species as the parent—how does it happen? And, the answer given is: species are like so many moulds into which the ovum is cast, even as molten metals are cast into the oven.

Caraka and Suśruta are of the opinion that in the fertilized ovum all organs are potentially present and they unfold in a certain order. Just as the bamboo-seed contains in miniature the entire structure of the bamboo, or the mango-blossom contains the stone, pulp and fibres which appear separated and distinct in the ripe fruit, so is the case with the fertilized ovum. Only the structures are so minute that they cannot be distinguished.[a]

In Caraka and Suśruta we meet with a theory, very much akin to the idea of pangenesis put forward by Darwin to explain the transmission of hereditary characters. Caraka assumes that the sperms of the male parent contain elements derived from each of its organs and its tissues, like 'gemmules' of Darwin or 'ids' of Spencer. Śaṅkara is of the same view, attributing to the sperm every organ of the parent organism in miniature, which holds *in potentia* the whole organism that is developed out of it.

To explain, then, why congenital deformities of parents are not transmitted to the offspring, Caraka has an ingenious explanation, attributed to Ātreya, which again resembles the theory propounded by Darwin. If the embryo derives its structure from every organ of the parents, why are congenital deformities like blindness, dumbness, lameness or any other similar defects not transmitted to the offspring? After all, the fertilized ovum is a miniature of all the organs and tissues of the parents. The difficulty is solved by the assumption that though composed of elements arising from the whole parental organism, the fertilized ovum is not influenced by the developed organs of the parents with their congenital or acquired idiosyncrasies. The parental *bīja* (seed) contains the whole parental organism in miniature but is independent of its developed deformed organs. Only if the *bīja* of an element representing a particular organ or tissue may happen to be defective or abnormal, the corresponding organ or tissue of the offspring will be similarly characterized; in other words, congenital deformities being somatic in character do not affect the germ plasm, and hence the normal and natural offspring.

The determination of sex of the offspring was another important question that engaged the thought of ancient Hindus.

The influence of nutrition on the characters of the *bīja*, specially as regards sex, health, colour, etc., of the offspring is freely admitted and various recipes and rituals were prescribed and practised to produce the birth of a male child.

It was generally believed that certain items of diet, ghee and milk for the male, and oil and beans for the female parents were favourable to the

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[a] *garbhasya sūkṣmatvāt nopalabhyante vaṃśāṅkuravat cūtaphalavacca* | *tadyathā cūtaphale paripakve kesarāmāṃsāsthimajjānaḥ pṛthak pṛthak dṛśyante kālaprakarṣāt* |

—*SS. Śā.*, 3.18.

bīja (seed). The sexual characters of the offspring were believed to follow a law of alternate rhythmic change with respect to the menstrual cycle of the female parent before conception. According to this belief fertilization of the ovum on the fourth day after the menses, or on the alternate days succeeding, was favourable to the foetus developing male characters, and on the fifth, seventh and alternate following days to the foetus developing into a female. Another factor determining sex of the offspring is the relative preponderance of the 'sperm and germ cells' in the fertilized ovum. Suśruta says, the birth of a male child marks the preponderance of semen over the ovum (in its conception); the birth of a daughter shows the preponderance of the female element. A child of no-sex is a product when ovum and sperm are equal (in their quality and quantity).[a] Translated into modern idiom of hormones this will very much read like 'preponderance of male hormones will tend to bring in maleness, that of the female hormones femaleness, the condition of sexlessness arising when the two hormones in the developing foetus are balanced'. Goldschmidt's experiments on sexuality on *Lymantria dispar* conducted during the first two decades of this century have produced results akin to what Caraka and Suśruta deduced about 1,600 to 1,800 years back without any apparent experimental aids.

In a recent publication, Verdi,[b] without quoting any authorities, writes: 'From time immemorial, there is a belief, in our land, about a link between determination of sex of human progeny and lunar phases. According to many, conceptions taking place during time periods between new moons and full moons—where the nights are called "luminous"—result in male children and conceptions taking place during time periods between full moons and new moons—where the nights are called "dark"—result in female children.

'However, some hold that contrary is true.'

COSMOGONY

The question of the origin of the world and life therein, which assumed great importance in the later Vedic period (specially in the *Upaniṣads*), had been raised even in the early *saṃhitās*. The tenth book of *Ṛgveda* has many hymns posing cosmogonical problems. These early speculations, though confused and larded with mythological and theological notions, are nevertheless interesting as the sources from which flew various streams of later thought.

Older ideas in the *Ṛgveda* about the world centred round creation, gods or individual deities having generated the world. The conception of a distinct creator different from, and superior to, all gods, appearing under the various names of *Puruṣa*, *Viśvakarman*, *Hiraṇyagarbha* or *Prajāpati*, was a later development. 'Whereas creation, according to the earlier view, is regularly referred to as an act of natural generation with some form of

[a] *SS. Śā.*, 3, 4–5.

[b] Verdi, p. 12.

the verb *jan* "to beget", these cosmogonic poems speak of it as the manufacture or evolution from some original material.'[a] In the well-known *Puruṣa-sūkta* (the hymn of man), this material constituting the world is *Puruṣa*, the thousand-headed and thousand-footed primeval giant covering the earth and even extending beyond it.[b] His head became the sky, his navel the air, his feet the earth; the moon, the sun and the wind springing respectively from his mind, eyes and breath. The germ of pantheism is inherent in the hymn, when it says that 'Puruṣa is all this world, what has been and shall be' and again 'one-fourth of him *is all creatures* and three-fourths are the world of the immortals in heaven'.

The *Puruṣa* assumes the role of the creator Prajāpati in the *Brāhmaṇas*, and in the *Upaniṣads* he is identified with the universe. Later, in the dualistic *Sāṃkhya* philosophy, *Puruṣa* is identified with the 'soul' as opposed to the matter.

In other hymns dealing with the origin of the world, creation is not the collective effort of gods, but of an individual creator. This agent of generation was the sun, 'the soul of all that moves and stands'.[c] Here we also see the first distinction between the mobile (*jaṅgama*) animals and the fixed (*sthāvara*) plants. Two cosmogonic hymns are addressed to the 'all-creating' *Viśvakarman*, probably synonymous with the sun, 'called by many names though one'.[d]

A much bolder step was the theory that the waters produced the first germ of things, the source of the universe and the gods.[e]

In another cosmogonic hymn of considerable beauty,[f] the primeval germ appears in the form of *hiraṇyagarbha*, the germ of gold, a notion doubtless suggested by the rising sun. Here, too, the waters are, in producing *agni*, regarded as bearing the germ of all life.

Two other cosmogonic poems explain the origin of the world philosophically as the evolution of the existent (*sat*) from the non-existent (*asat*). In the somewhat confused account given in one of them,[g] three stages of creation may be distinguished; first the world is produced, then the gods and lastly the sun.

These ideas are presented more forcefully and beautifully in the Creation Hymn:[h]

> Then was not non-existent nor existent: there was no realm of air, no sky beyond it.
> What covered it, and where? and what gave shelter? Was water there, infathomed depth of water!
> Death was not then, nor was there aught immortal: no sign was there, the day's and night's divider.
> That One thing, breathless, breathed by its own nature: apart from it was nothing whatsoever.

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[a] Macdonell, p. 132.
[b] ṚV., X, 90.
[c] ṚV., I, 115.
[d] ṚV., X, 81–82; I, 164.46.
[e] ṚV., X, 82.
[f] ṚV., X, 121.
[g] ṚV., X, 72.
[h] ṚV., X, 129.

Darkness there was: at first concealed in darkness this All was indiscriminated chaos.
All that existed then was void and formless: by the great power of warmth was born that unit.
Thereafter rose Desire in the beginning, Divine, the primal seed and germ of spirit.
Sages who searched with their heart's thought discovered the existent's kinship in the non-existent.
Transversely was their severing line extended; what was above it then, and what below it?
There were begetters, there were mighty forces, true action here and energy up yonder.
Who verily knows and who can here declare it, whence it was born and whence comes this creation?
The gods are later than this world's production. Who knows then whence it first came into being?
He, the first origin of this creation, whether he formed it all or did not form it.
Whose eye controls this world in highest heaven, he verily knows it, or perhaps he knows not.[a]

Apart from its literary merit, this poem is most noteworthy for the daring speculations which find utterance in so remote an age. Being the only piece of sustained speculation in the *Ṛgveda*, it is the startingpoint of the natural philosophy which assumed shape in the evolutionary *Sāṃkhya* system. It will, indeed, ever retain general interest as one of the earliest specimens of the Aryan philosophic thought. With the theory that, after the non-existent had developed into the existent, water came first and then intelligence was evolved from it by heat, the cosmogonic accounts of the *Brāhmaṇas* substantially agree. Here, too, the non-existent becomes the existent, of which the first form is the water. On these floats *hiraṇya-garbha*, the cosmic golden egg, whence is produced the spirit that desires and creates the universe. Always requiring the agency of the creator Prajāpati at an earlier or at a later stage, the *Brāhmaṇas* in some of their accounts place him first, in others the water. The fundamental contradiction, due, perhaps, to mixing up the theory of creation with that of evolution, is removed in the *Sāṃkhya* system by causing *Puruṣa*, or soul, to play the part of a passive spectator, while *Prakṛti*, or primordial matter, undergoes successive stages of evolutionary development. The cosmogonic hymns of the *Ṛgveda* are thus not only the precursors of Indian philosophy but also of *Purāṇas*, of which one of the main objects is to describe the origin of the world and life therein.

ANIMALS AND NATURAL HISTORY IN THE MEDIEVAL PERIOD

The trail blazed by ancient Indian naturalists tapers into the medieval period without much variations on the theme. The advent of the Muslims, particularly of the Moghuls from the sixteenth century onwards, added a new perspective to the study of animals, inasmuch as they attemped to record

[a] Translated by Griffiths, II, pp. 575–76.

observations made by themselves, or by others after careful verifications as far as possible. This transition is reflected in some of the important Sanskrit works of this period, followed by the memoirs of the Moghul kings. Of the Sanskrit works, the *Mānasollāsa*, composed by King Someśvara, deserves special mention. This interesting encyclopaedic work deals with recreation and describes in detail various modes of relaxation which include topics like drawing, painting, iconography, gardening, culinary art, cock-fighting, hunting, fishing, etc. Hora[a] has published an English translation of the fourteenth chapter of *Mānasollāsa* entitled *Matsya-vinoda* (the sport of angling). Someśvara gives a classification of sporting fishes as scaly and scaleless, lean and thin, and those living in sea or in rivers. He names 37 fishes, where they live and what they feed on. Furthermore, he deals with lines, hooks and baits suitable for various types of fishes, and advises on the sport of fishing. This work, according to Hora, is rich in factual and deductive knowledge which in some respect remains unsurpassed even now.

The only Indian work which may be said to deal exclusively with zoology is Haṃsadeva's *Mṛga-pakṣi-śāstra*, written in the thirteenth century A.D., at the behest of the Jaina King of Jinapura, Saudadeva, who, fascinated by the beauty of animals in forests, decided to stop hunting and to acquire knowledge about them. Haṃsadeva's account of beasts and birds can by no stretch of imagination be called scientific; rather his emphasis is on the love-life of animals, their temperament (based strictly on the three *guṇas—sattva*, *rajas* and *tamas*—of the philosophical system), their size, colour, etc. Nevertheless, the book represents the first attempt in India at large-scale description of animals of which the nomenclature as adopted by him is drawn almost exclusively from the Sanskrit literature of the middle and ancient ages. He describes six kinds of lions, three of tigers, two of hyenas (which he also calls leopards), three of bears, two of rhinos, thirteen of elephants, seven of horses, four of camels, three of asses, three of boars living in forests and seven living in country and villages (with which he confuses porcupines), five of buffaloes, etc. His list of birds is fairly long. In spite of the rather inaccurate treatment, one can discern accuracy of description of features helpful in identification. The many varieties listed are no doubt inspired by the synonyms, each of which has been erroneously treated as a separate kind. Furthermore, information about periods of gestation, longevity, etc., is based more on hearsay than on factual observations.

Śukranīti

Anatomical details on the domestic animals, like the elephant, horse, cattle, etc., were mostly confined to the external morphological characters like the colour of body, colour of hair, proportions of body-parts, gait, temperament, etc. B. K. Sarkar has ably summarized the information on these aspects of elephants and horses available in ancient texts, specially

[a] Hora (3 ii), pp. 145–69.

in the *Śukranīti*. The assessment of the external characters of these animals was chiefly done from the practical point of view, to distinguish between the different qualities of animals in relation to their usefulness, and various breeds were enumerated taking into consideration the external characters of practical importance.

The Muslim Period

The Muslim rulers of India, in their own way, were sportsman-naturalists. They were keen hunters and had big menagerie of horses, dogs, cheetahs, falcons, etc., which were primarily helpful in hunting. Few, however, have left records which could throw light on the fauna of the country or its natural history. The only exceptions are the Moghul kings whose memoirs and biographies bring to light interesting information about the fauna and flora of the period. Ali in a series of articles has given a lucid account of the love of nature of the six great Moghul kings, Babur to Aurangazeb. Apart from their keen interest in animals and nature, the Moghul rulers were particular about truthfulness and accuracy in their memoirs.

Babur, after his victory at Panipat in A.D. 1526, proceeded to compile a comprehensive gazetteer of Hindustan, to describe at length the customs of peoples, animals, fruits and flowers of the land he had conquered. In recording his observations he had taken special care for their authenticity and accuracy. Even when engaged in affairs of the State, or marching against a foe, Babur was always awake to the objects around him, and anything new that he saw was carefully noted mentally and reduced to writing in his memoirs at the earliest opportunity. Of the larger mammals, he was very fond of hunting the rhinoceros, an animal he had not seen in his native land. He frequently hunted the rhinos in the jungles of Peshawar and Hashnagar.

Humayun (1530–1540, 1555–1556), in his chequered career, had but little time to indulge in hunting animals. Yet his deep love of animals and nature is reflected in little passages of *Tazkerech*.

Akbar (1556–1605) was passionately enamoured of animals of all kinds from Persia, Turkestan and Kashmir. The inmates of his menagerie, which were every day led past under the royal window for the monarch's observation, included horses, elephants, antelopes, nilgais, rhinoceroses, large buffaloes with prodigious horns, lions, tigers, some of the finest sporting dogs of every kind from Uzbek, and species of birds of prey used in field sports for catching partridges, cranes, hares, and even for hunting antelopes on which they pounced with violence.

Moreover, he was a great breeder of domestic animals—elephants, camels, cows and horses—and the breeds of horses produced in his stables were as fine as those of Arabia.

His mode of hunting most frequently employed was *quamargah* or 'ringing in' method. He employed his armies (which kept them trim in



Bengal florican, painted by Mansur, court-artist of Emperor Jahangir, in *c.* A.D. 1624.
(Courtesy, Indian Museum, Calcutta.) *See* page 441

PLATE VIII



Siberian crane, painted by Mansur, court-artist of Emperor Jahangir.
(Courtesy, Indian Museum, Calcutta.) *See* page 441

times of peace) to surround vast tracks of the countryside, gradually closing in, and driving the game towards the centre of the ring where the royal hunters lay in wait.

The Game Department of Akbar maintained a record of all animals hunted, with measurements and the minutest details concerning them. He possessed a remarkably large number of cheetahs or hunting leopards (about 9,000), a species now extinct from India, and 'lynxes' (? caracal), in addition to a large variety of good hunting dogs. His birds of prey, trained in sport, were the *bāz* (*Accipiter gentilis*), *shāhin* (*Falco peregrinus*) and *shunqar* (*Falco biarmicus*) and *burquat* falcon (probably the golden eagle, *Aquila chrysaetos*). The Emperor, however, preferred the *bashāh* (sparrow-hawk, *Accipiter nisus*), which was given various names by him.

Jahangir (1605–1627) was the greatest naturalist among the Moghuls, just as his father was the greatest Emperor. 'His profuse and engrossing memoirs are a veritable natural history of the animals that came under his notice, and a record of the most searching observations concerning them.'[a] For exhaustive account of Jahangir as a naturalist, Alvi and Rahman's book may also be referred to (Alvi and Rahman (2)). In this monograph the authors have ably brought together all available information about this particular fact of Jahangir who could have been a better and happier man as the head of a natural history museum.

His love for animals was so widely known that foreign dignitaries often gave him presents of exotic animals, and his court artists, specially Ustad Mansur, were kept busily engaged in drawing the likeness of animals and other objects that came to the Emperor or to his notice. Mansur excelled in the art of animal and floral portraiture, as accurate and meticulous as their literary records maintained by the Emperor. Many of the animal paintings made by the court artists of Jahangir have been lost, but whatever has survived (scattered in several museums and private collections) can be of great utility to modern taxonomists and naturalists for their accuracy of representation (Pls. VII, VIII, IX).

Though not a trained zoologist, Jahangir's keen powers of observation and passion for knowledge imparted to his descriptions an objective thoroughness characteristic of modern scientific writing. In describing organisms observed by him, he gave local names, geographical distribution and even structural characteristics, weights, measurements and some interesting notes on ecology and behaviour. Though characterized by an overtone of the admiration for beauty or a feeling of repulsion for an ugly animal, his descriptions were often precise enough for the correct scientific identification of the objects described. His studies of the sarus crane, and the gestation period of the elephant, are two amongst his original contributions, and his observations on the ecology, behaviour, etc., of animals generally might come under the same category as 'the first records' of modern zoological writers.

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[a] Ali, p. 841.

Jahangir maintained a big aviary and menagerie where he carried on his observations, tests and experiments. His curiosity and passion for verifying hearsay often led him to dissect objects of his hunt and to examine the internals. He was specially interested in the position of the gall-bladder and never failed to verify whether this organ was situated inside the liver or outside. It may be of interest to note that what was just a natural curiosity for Jahangir assumed great importance some 300 years later. From the functional and evolutionary points of view, the presence or absence, size and position of gall-bladders in various animals formed topics of extensive investigations during the third and fourth decades of the present century. He was also keen to study the reproductive behaviour of animals in captivity and recorded some interesting observations on the breeding of the cheetah and of the tiger in captivity. Equally interesting are his observations on the diet of the Indian python (*Python molurus*) 'which can swallow up to a hog-deer' and of the king-cobra (*Ophiophagus hannah*) which was seen swallowing another cobra.

Jahangir's repute as a hunter was no less than his passion for nature, and his records reveal astronomical figures, 3,203 mammals and 13,954 birds. The nilgai (889), and deer, antelopes, mountain goat, etc. (1,670), among mammals, and pigeons (10,348) and crows (3,276) appeared to be his special targets.

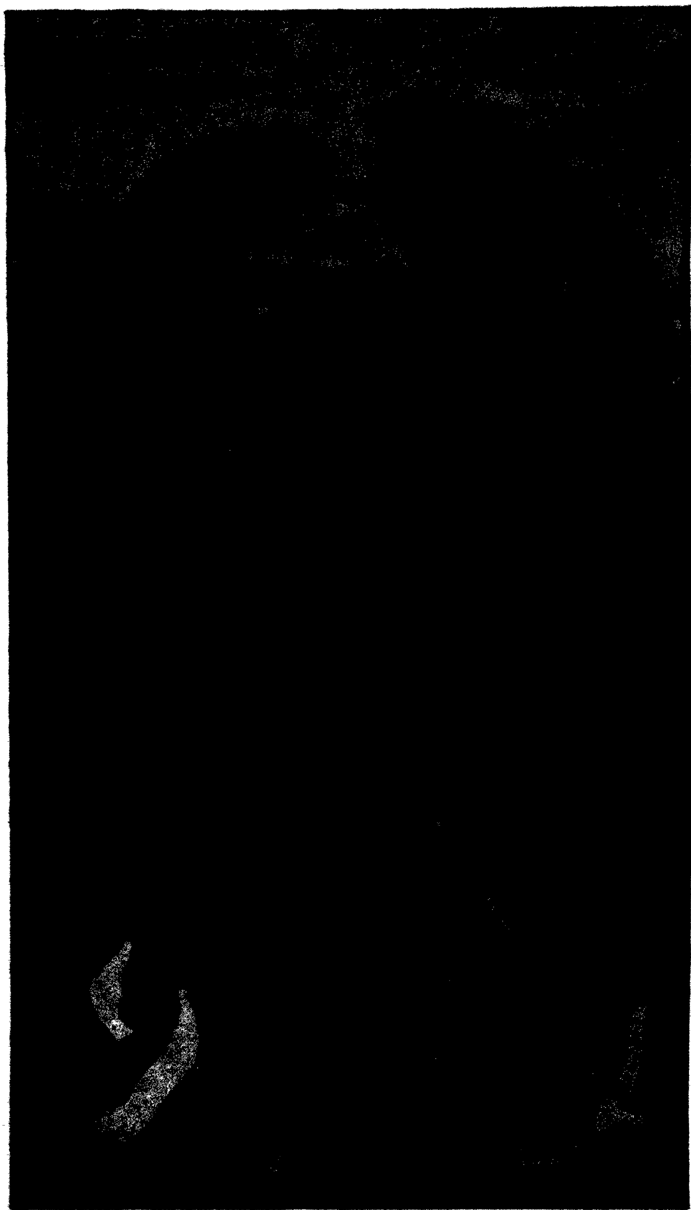
The two last eminent Mughal kings, Shah Jahan and Aurangzeb, did inherit the qualities of their ancestors, but not to the same extent as Jahangir's or Akbar's.

The animals mentioned in the memoirs of the Moghul kings have been listed by Ali, along with notes recorded by them. Jahangir's animals have also been dealt with by Alvi and Rahman. Of special interest in this connection is the find of a miniature portrait of the dodo (a bird from Madagascar now extinct) in the collection of the Institute of Orientalists of the USSR, Academy of Sciences. This remarkable miniature (Pl. IX), apparently drawn from a live specimen, though unsigned and undated, bears the unmistakable Mansur style and was probably drawn from a collection of three birds in the possession of the East India Company's Factory at Surat where it was observed and described by Mundy in 1628.

ANIMALS IN *SAṄGAM* LITERATURE OF THE TAMIL COUNTRY

The Tamil country of the south is also rich in literature on animals and their natural history. Rao[a] has dealt with the animals mentioned in the ancient Tamil *Saṅgam* literature. This literature was certainly spread over a long period, which according to estimates lasted from 3000 B.C. to A.D. 1915. Nīlakaṇṭha Śāstrī (*vide* Rao), however, is of the view that this literature was spread over four centuries commencing with the fourth century A.D.

[a] Rao (H. S.), pp. 251–80.



Miniature of the dodo and a few other birds, painted during the reign of Emperor Jahangir. (First published in *Journal für Ornithologie*, 1958, Vol. 99; blocks received through the courtesy of Prof. Dr. Erwin Stresemann, Berlin). *See* p. 441

A great variety of mammals and birds and a few species of reptiles and fishes and of arthropods have been mentioned, 'not in special treatise dealing with their natural history, but only incidentally in the course of descriptive accounts in verse or prose of town and country, of crowns and kingdoms and of wars and conquest'.[a] Wild as well as domestic forms are mentioned.

Among the mammals referred to, the wild beasts, viz. lion, tiger, wild cat, bear, boar, porcupine, elephant, monkey, deer, wild cow or bull, jackal, mongoose, hare, squirrel and rats, find mention. The domestic forms



FIG. 12. Mythological '*yali*', the composite beast of the Tamil country (after Rao, 1957).

include goat, sheep, pig, cow, bull, buffalo, the beasts of burden such as the ass, mule and horse, and the elephant, camel, dog and bitch. Mythological *yali*, the composite beast, also figures (Fig. 8.12).

[a] Rao (H. S.), pp. 251–80.

The reptiles of the *Saṅgam* literature comprise the cobra, python, tortoise and turtle, crocodile, lizard and monitor. The mythical (or freak?) five-headed cobra is also referred to.

The soaring birds such as the kites (including *garuḍa*) and vulture, domestic and jungle fowl, crow, sparrow, pigeon, parakeets, peacock, koel, skylark, kingfishers, various kinds of owls, swan, crane and sea-gull are also mentioned.

Only a few fishes (including the shark) are mentioned, and the only Crustacea referred to is a crab. Ant, bee, wasp and dragon-fly and the winged Isoptera—the white ant or termite—and the louse among insects, and the scorpion among other arthropods, find mention.

The descriptive account of animals in the *Saṅgam* tamil period is a mixture of observed facts, imagination and poetic fancy, not a serious study in a natural history. Most of the animals mentioned in this literature also occur in the Vedic and post-Vedic literature of north India.

9 THE PHYSICAL WORLD: VIEWS AND CONCEPTS

B. V. SUBBARAYAPPA

INTRODUCTION

IN the perspective of history, the ancient inquiries concerning the nature of the physical world seem to have two characteristics, viz. (i) they had almost similar types of origins and patterns of development in more than one culture-area; and (ii) not a few of the ancient metaphysical concepts, though intuitive, appear to be near approximations to some of the modern physical ideas arrived at by methods of induction, deduction and experimentation. In different periods of history man, the thinker, very often turned his attention to that elusive problem—the problem of One in Many—in other words, to the plausible explanation of the maximum of phenomena by the minimum of postulates. That in this way the physical world is capable of human understanding has been the tacit premise of the ancient thinkers and men of modern science alike. In ancient times, nevertheless, the attempt was at a rational and knowable interpretation of the physical world and seldom at manipulating it towards the material benefits of man. This attitude manifested itself in different speculations or conceptual schemes and, in the evolution of the latter, logic and deduction played a dominant role. Even so, the world-view, as it may be called, of the ancient thinkers was not the one which was exclusive of man himself. The knower and the known, man and the world, the individual spirit and the cosmic spirit were integrated in some form or the other.

In its earlier phase this man-spirit-cosmos view, indeed a wider and richer view of the world which was prevalent in different culture-areas, was often mixed up with mythological elements. Gradually it became freed from its mythological shackles and acquired a rational or intellectual foundation. It was a struggle of *logos* against *mythos*, the former steadily gaining ground over the latter. In so emerging the world-view assumed another phase. It became intertwined with the philosophical system or systems of the culture-area. In addition, now and then in the Middle Ages, theological implications too made inroads into the otherwise rational world-view. In the history of science the views and concepts of the physical

world coming to the forc, both intuitively and on logical grounds, should be understood in this light. To illustrate what has been stated above the two good examples are the speculative inquiries of the Indians and of the Greeks.

Let us consider the Greeks first.[a, b] The early Greek thinkers attempted for the first time to give a rational interpretation of the natural occurrences. Some of them tackled the problem of one in many, of finding the single 'principle', 'substance' or 'essence', which could explain all the observed phenomena. Thales of Miletus (*c.* 624–565 B.C.) thought that water was the 'substance' or primal matter which would remain unchanged amidst all observed modifications. Obviously he had observed how water would change, flow without any shape or colour and undergo a cycle of movement on earth and in air. He conjectured that there was a substance (water) 'from which all other things came to be, it being conserved'. That water was the primordial substance was known to the Babylonians. But they had imagined it in a mythological setting. But Thales of Miletus discarded the mythological element and tried to interpret the natural happenings in the universe of matter in terms of a single substance. In consequence he became the stimulator of a system of Greek philosophy and of attempts at formulating unitary conceptions.

Following on, another Milesian philosopher, Anaximander (*c.* 611–575 B.C.), speculated on the essential unity of matter and assumed, as the first principle, an unlimited substance (Infinite), a qualitatively undetermined eternal matter in motion (*apeiron*). Yet another Milesian philosopher, Anaximenes, specified the concept of Anaximander by saying that the first principle was 'air' (*pneuma*) with dynamic qualities (perpetual motion). Later Anaximenes, a contemporary of Anaximander, thought that the process of condensation or rarefaction caused transformations of the primary substance into various others. Heracleitus of Ephesus (*c.* 540–475 B.C.) regarded 'fire' as the fundamental principle in an ingenious way. He thought that the world was one and at the same time many. He held that the whole world was in a flux of change, and change alone was real. 'Fire' was representative of this change and so it was the fundamental principle. As against this Parmenides of Elea in South Italy regarded change as illusion and introduced the concept of One.

From these unitary conceptions, each of which had its inherent deficiencies to account for all the observed phenomena, a pluralistic presentation was put forward by the Sicilian philosopher Empedocles (*c.* 500–430 B.C.). Adding 'earth' as the fourth principle, Empedocles sought to explain the multiplicity of phenomena in terms of earth, water, air and fire. He called them the 'roots of the world'. He also introduced the idea of force eternally acting on these 'roots' in a speculative way, in terms of love and strife and held that they were responsible for all combinations and separations respectively. He went a step further and main-

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[a] Singer, pp. 8-26. [b] Taton, pp. 180–98.

tained that these 'roots' were causes of all occurrences even in macrocosm. Anaxagoras, a contemporary of Empedocles, assumed a number of infinitely small 'seeds' (Aristotle called them *homeomeres*) of infinite variety in infinite space, subject to the action of mind or breath (*nous*) which directed production, evolution and dissolution of the world. This type of speculation reached another stage when Leucippus (fl. *c*. 475 B.C.) and Democritus (*c*. 470–400 B.C.) postulated an atomic view of the substance and said that atoms were of the same substance, but of different sizes and shapes. The Greek atomism, needless to add, was one of intuition.

The author of the 'Principle of Uncertainty' in modern physics, Werner Heisenberg, in his observation on the foregoing Greek conceptions, remarks that 'some statements of ancient philosophy are rather near to those of modern science. This simply shows how far one can get by combining the ordinary experience of nature that we have, without doing experiments with the untiring effort to get some logical order into this experience to understand from general principles'. According to Heisenberg, the 'Fire' of Heracleitus corresponds to the modern concept of energy, 'for energy is a substance which moves and from which all things are made'. Further, he holds that as the atoms of Democritus are devoid of qualities, have extension in space, and motion, the 'neutron' of modern physics resembles the former. But he warns that 'this comparison should not be misunderstood. It may seem at first sight that the Greek philosophers have by some kind of ingenious intuition came to the same or very similar conclusions as we have in modern times only after several centuries of hard labour with experiments and mathematics . . . There is an enormous difference between modern sciences and Greek Philosophy, and that is just the empiristic attitude of modern science '.[a]

In India, the first monistic principle expressed in the *Ṛgveda Saṃhitā*, the oldest literary record of the Vedic Age, is 'water'. Later in the *Upaniṣads*, in a progressive way, the doctrine of five elements took shape. As this aspect of the Indian world-view is discussed in the following pages, details of the gradual unfolding of this doctrine are not presented here. There are, however, noticeable differences between the Empedoclean theory of four elements and the Indian doctrine of the five elements. What is important, nevertheless, is the notable commonness of attempt at reducing the knowable phenomena into the interplay of four or five elements respectively. In both, the fundamental principles like earth, water, etc., had not only their philosophical implications but also assumed a plural presentation. Like the Greeks, Indians also developed an atomic theory. The Indian atomic theory, from its simple beginnings, became a favourite frame of protracted discussion, as will be seen later, among the Indian speculative philosophers. Logic and causal considerations occupied a pride of place in these discussions. Similarly, Leucippus, the originator of the Greek atomic theory, is believed to have stated that 'Nothing occurs

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[a] Heisenberg, pp. 58–70.

by chance, for there is a *reason*, a necessity for everything'. Unwavering dependence on reason, on the relation between cause and effect shaped the speculative inquiries of both the Greek and the Indian thinkers.

Such as they are, the speculative enquiries lay stress on one historically important factor, namely both India and Greece developed the most consistent and logical theories discernibly on parallel lines. Richard Garbe writes: 'The historical possibility of the Grecian world of thought being influenced by India through the medium of Persia must unquestionably be granted, and with it the possibility of the above-mentioned ideas being transferred from India to Greece.'[a] However, other scholars like Max Müller and Paul Deussen suggest that the developments are independent. Even so the remarkable resemblances in the Indian and Greek theories of matter cannot be brushed aside.

In one respect the Indian speculative inquiry seems to have gone a step ahead. It relates to what is known as the conception of 'substance'. In the ancient period, the conception of 'substance' was a part of the general inquiry into the intelligible reality. The two Greek thinkers, Plato (427–347 B.C.) and Aristotle (384-322 B.C.), inquired into this aspect, and each put forward a different conception of substance. Plato conceived of it as the Universal Idea which, he thought, existed apart from the things of the world. Aristotle imagined it as potentiality with no independent existence. He enunciated that matter was potential and form was actual. He thought that the Empedoclean 'elements' were different aspects of primary matter (*protyle*) in which all the knowable forms of matter were potentially contained.[b] The Aristotelian conception of substance, with some modifications, formed the basis for interpreting the phenomena even till the beginnings of modern science (about seventeenth century A.D.). The point worthy of noting is that both in medieval Europe which inherited Aristotelian philosophy and in India which developed on its own a number of systems of inquiry, the conception of substance received considerable attention.

Of special interest is the conception of substance of the *Vaiśeṣika*, one of the six orthodox systems of Indian thought. The *Vaiśeṣika* conception was elaborated later by the exponents of not only the *Vaiśeṣika* school but also by the followers of the *Nyāya*, another Indian orthodox system of thought. The *Nyāya-Vaiśeṣika* conception of substance seems to be unique. It includes the five elements (earth, water, fire, air and *ākāśa*), space and time, self and mind—nine in all. It is pluralistic presentation consisting of the material and the non-material, the finite and the ubiquitous, and the conscious self as well as mind in an ingenious way. The *Nyāya-Vaiśeṣika* system accepts the multiple character of reality and holds substance as one of the reals. Each of the nine, as mentioned above, is called substance again and thus there are nine substances. All the same, they are integrated with the generic conception of substance.

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[a] Garbe (3), p. 38.

[b] Taton, p. 231.

The inclusion of space, time, self and mind in this generic conception of substance has a far greater import from the standpoint of the modern scientific epistemology. The latter which tries to throw light on the nature and structure of modern scientific knowledge, particularly about the physical world, is still unable to steer clear of the conceptual inadequacies concerning substance. What is substance? This question with its contestable character has remained still unsolved by modern scientific epistemologists. This is evidenced by the vicissitudes through which the problem of matter has passed as a result of scientific investigations in the last century and half, viz. the law of conservation of mass, the law of conservation of energy, the fundamental particles, wave nature of electron, energy-matter relationship and the like.

The scientific approach takes cognizance of the 'observables' and the associated causal mechanism; the unobservables are outside its province. The observational procedure deliberately excludes the observer; for the latter, the subjective element, is believed to run counter to the objective investigation based on the scientific methods of experimentation, induction and deduction. The exclusion of the subjective element (i.e. a complex mechanism involving the notion of 'I', mind, senses, nerve impulses and other determinants of observation) which is an integral part of the observational procedure seems to have come in the way of arriving at the conception of substance by the modern scientific epistemologists. The fact is that the observer *participates* in the methods of observation and necessarily the self and mind of the observer would also constitute the determinants of observation. If the observational procedure were to lead to the comprehension of substance or the *world-stuff*, it has of necessity to be inclusive of these determinants. In this respect the *Nyāya-Vaiśeṣika* conception of substance with its causal garment merits serious attention. The foregoing discussion, though brief, may be kept in mind while understanding the different speculative inquiries of the Indian thinkers, who have tried in their own way to present a view of the physical world, in the history of scientific ideas.

It must be noted that the Indian physical concepts, in their origin and ramification, have been an integral part of the Indian religio-philosophical systems, both orthodox and heterodox. For, within the confines of the respective philosophical positions alone the physical concepts attempt to explain the material world. The Indian thinkers believed that the special knowledge as contained in the different sciences was always relatively real and gave only the glimpse of the Absolute. Real knowledge, they thought, was necessary to realize the Absolute. Obviously towards this end they speculated on what may be called the interrelatedness of things and the thought processes associated with them.

MAIN LITERARY SOURCES

Even though the physical concepts of the Indian thinkers are in point of fact bold and imaginative, strangely there are no Indian texts which

exclusively deal with them. Each system of Indian thought has built up its own physical and metaphysical views. One has to go through a voluminous literature to locate the origin and trace the evolution of the Indian physical concepts. The Vedic literature (the four *Saṃhitās*, *Brāhmaṇas*, *Āraṇyakas*, *Upaniṣads* and the *Vedāṅgas*); the *Purāṇas*, epics and *itihāsas*: the literature of the *Nyāya-Vaiśeṣika*, *Sāṃkhya*, *Yoga* and the *Mīmāṃsās*; the Buddhist and the Jaina texts; the tantrik literature; works on *Āyurveda* and astronomy are among the important literary sources which contain the fundamental as well as evolved physical ideas of Indians over a long period—perhaps stretching to about two thousand years. The literature is as varied as it is vast; for even in the works of a particular school of thinking the conceptual scheme relating to certain physical concepts like atomism, space and time, presents a wide spectrum of ideas. Nevertheless, it would be wrong to conclude that the speculations are an ensemble of dogmatic, complex assertions. On the other hand, they are refreshingly noted for their logical structure cast in a well conceived and rigorously balanced causal sequence. In essence, then, they are logical postulates.

Among the main literary sources those which expound one of the systems of Indian thought, viz. the *Vaiśeṣika*, are very important from the point of view of the physical concepts. The *Vaiśeṣika sūtra* of Kaṇāda and the *Padārthadharmasaṃgraha* of Praśastapāda are the two principal authorities of the *Vaiśeṣika* school. Though a gloss on the *Vaiśeṣika sūtra*, the *Padārthadharmasaṃgraha* has the characteristics of an original work. The *Vaiśeṣika* school is supposed to have been propounded by a sage called Kaṇāda. Kaṇāda, Kaṇabhuj or Kaṇabhakṣa, as he is differently referred to, means one who eats particle or grain, indicating probably the atomic particles; and this is attributed to the fact that Kaṇāda enunciated the essentials of an atomic theory.[a] The *Vaiśeṣika*, even in its *sūtra* form, is very old, possibly pre-Buddhistic.[b] However, the origins of the *Vaiśeṣika sūtras* are obscure. There are reasons to believe that the *Vaiśeṣika* school in its beginning was heterodox in position not taking shelter under the umbrella of orthodox Vedic views. Later it appears to have absorbed the Vedic concept of *dharma* and thus entered the orthodox fold.[c] Nevertheless, it is rather important to note that the *Vaiśeṣika* recognizes both perception and inference as means of acquiring knowledge and does not accord a pride of place to the authority of the Vedic tenets.

In its ten chapters the *Vaiśeṣika sūtra* of Kaṇāda deals with a number of physical concepts, the most important of which are those concerning substance, motion, attributes, space, time and atomism. These were developed later by a number of followers of the *Vaiśeṣika* and the *Nyāya* schools. By about the tenth century A.D. the two schools began to be recognized by a syncretic nomenclature, the *Nyāya-Vaiśeṣika*. The *Vaiśeṣika* and the *Nyāya* schools developed a theory of causation known as *ārambhavāda*. The two significant aspects of the *ārambhavāda* are: (i) that the cause

[a] Ui, pp. 4 ff. [b] Das Gupta (S. N.), I, pp. 281–82. [c] Hiriyanna (2), pp. 39–40, 84.

and the effect are different and (ii) that there is a continuity (*sānvayata*) between the two. In this process of thinking the relation between the *whole* and its *parts* is rather interesting. The whole, when it comes into existence, is non-existent as separate parts; for as an effect it has a new beginning. Yet when the whole is destroyed the parts exist, and the parts have altogether a different significance. The important physical concepts of the *Nyāya-Vaiśeṣika* in general and the atomism in particular are based upon this theory of causation.[a]

Apart from the *Vaiśeṣika sūtra* and the *Padārthadharmasaṃgraha* of Praśastapāda, the other *Nyāya-Vaiśeṣika* texts which contain significant accounts of the Indian physical concepts and deserve special mention are: *Nyāya-sūtra* by Gautama (*c.* fourth century B.C.); *Nyāyabhāṣya* by Vātsyāyana (*c.* fourth century A.D.); *Nyāya-vārttika* by Udyotakara (seventh century A.D.); *Nyāyasāra* by Bhāsarvajña (eighth century A.D.); *Nyāya-vārttika tātparyaṭīkā* by Vācaspati Miśra (ninth century A.D.); *Nyāyamañjarī* by Jayanta Bhaṭṭa (ninth century A.D.); *Vyomavatī* by Vyomaśivācārya (*c.* ninth century A.D.); *Kiraṇāvalī* by Udayana (tenth century A.D.); *Nyāya-kandalī* by Śridhara (tenth century A.D.); *Saptapadārthī* by Śivāditya (eleventh century A.D.); *Nyāyalīlāvatī* by Vallabhācārya (twelfth century A.D.); *Nyāyasiddhāntadīpa* by Śaśadhara (twelfth century A.D.); *Tattvacintāmaṇi* by Gaṅgeśa Upādhyāya (thirteenth century A.D.); *Upaskāra* and *Kaṇāda-rahasya* by Śaṅkara Miśra (fifteenth century A.D.); *Padārthatattva nirūpaṇa* by Raghunātha Śiromani (sixteenth century A.D.); and *Bhāṣāpariccheda* and *Nyāya-muktāvalī* by Viśvanātha (seventeenth century A.D.).[b]

Of the Jaina texts, Umāsvātī's *Tattvārthādhigamasūtra* (second century A.D.); *Bhagvatī Sūtra* (*c.* fourth to fifth centuries A.D.); Siddhasena Divākara's *Nyāyāvatāra* (sixth century A.D.); Nemicandra's *Dravyasaṃgraha* (twelfth century A.D.); Mallisena's *Syādvādamañjarī* (thirteenth century A.D.) are important. Among the noted Buddhist works are *Saṃyutta Nikāya*, *Dhamma-saṅgaṇi*, Buddhaghoṣa's *Atthasālinī* and *Visudhimagga* (*c.* fifth century A.D.); Vasubandhu's *Abhidhammakośa* (fourth to sixth centuries A.D.); *Abhi-dhammamatthasaṃgraha*; Diṅnāga's *Pramāṇasamuccaya* and *Nyāyapraveśa* (sixth century A.D.) and Dharmakīrtti's *Nyāyabindu* (seventh century A.D.).

In this short account an attempt is made only to present a bird's-eye view of the important physical concepts of the Indian thinkers as contained in the literary sources. Perhaps it would have been appropriate if a period-wise presentation of these concepts and conceptual schemes was attempted bringing to the fore at the same time their originators. In the present state of knowledge it is feared that such an attempt may result in historically tantalizing inaccuracies. In view of this, what follows is a broad historical outline of the significant views and concepts of the Indians concerning the physical world. Later, they are discussed under such heads as are relevant to our purpose.

[a] Bhaduri, 4 and 12.

[b] Gopinath, pp. 1–85.

Indian Physical Concepts in Ancient and Medieval Periods
(An Outline)

c. 2000–1500 B.C.	*Ṛgveda* Emergence of monistic ideas—*Viśvajyoti* (cosmic light) as principle of life, soul of all gods and the essence behind all manifestations; *ṛta* (natural law) as transcendental and unitary principle of all motions; *yajña* (sacrifice) as connective dynamic principle and nucleus of all evolution; and *ap* (primeval water) as the supra-sensible first cause.
c. 700–600 B.C.	*Upaniṣadic literature* Step by step evolution of the doctrine of five elements (*pañcamahābhūtas*), concepts of space and time leading to a progressive understanding of Brahman as the Universal Spiritual Principle.
	The Vaiśeṣika school Aphoristic conceptual presentation relating to substance, qualities and motion; the five elements, space and time among the reals; atomism; the *ārambhavāda* as a theory of causation to include phenomenal knowledge.
c. 600–200 B.C.	*Buddhism and Jainism* New approach to the problem of matter and motion.
	The Cārvāka school Direct perception as the only means of knowledge; acceptance of the theory of four elements (earth, fire, water and air).
c. 200 B.C.–A.D. 400	*Systematic formulations of the Vaiśeṣika, Nyāya, Mīmāṃsā and Sāṃkhya.* Integrated view of substance; examination of the means of knowledge; the real and the unreal about space, time and sound.
	The Jaina and the Bauddha literature Atomism finding new adherents among the Jainas; the doctrine of momentariness of the Bauddhas and the problem of matter; atoms and qualities as force; space and time in relation to matter and atoms.

c. A.D. 400–1200 *Commentaries on orthodox and heterodox original works*

Doctrine of elements finding newer interpretations; fresh ideas about atom, space and time according to some Bauddha and the Jaina schools; atoms-dyads-triads, motion, heat, light and sound finding elaborate expressions at the hands of commentators of the *Nyāya-Vaiśeṣika* and the *Mīmāṃsā* schools within the meaning of the original notion; concepts of *pīlupāka* and *piṭharapāka*; sense-contact theory of perception of objects; views on production, destruction and eternality of sound.

c. A.D. 1200–1800 *Rise and spread of neo-logic (navya nyāya) in eastern India*

Physical concepts becoming intertwined with the theory of knowledge and kindred logical questions; new meanings of space, time and atomism in relation to the Supreme.

UNIVERSAL CONCEPTIONS

COSMIC LIGHT, *ṚTAM* AND *YAJÑA*

To start with, it is rather necessary to make a brief reference to certain universal conceptions which are found in the Vedic literature. A striking feature of the *Ṛgveda* is its attempt to discover the essence or the power that is behind all manifestations.[a] In this respect the conception of cosmic energy or cosmic light as dealt with in the *Ṛgveda* deserves special mention. The unmanifested is cosmic energy, and the manifested is cosmic light. The latter is referred to as *Viśvajyoti*, which is a positive unitary principle, pure and sublime. In fact, the Vedic gods and their functional attributes are to be understood in terms of cosmic light. The *Ṛgveda* says that gods worship the cosmic light as the principle of life and longevity, and that the cosmic light is the 'soul of all gods' and the 'womb' of all created things.[b] *Aditi*, which means the boundless or the unbounded and which according to the *Ṛgveda* is the substratum (pure consciousness of infinite existence) of all that is here and beyond, is the Light-Infinite.[c] Gods who are born of *Aditi* are manifestations of the Infinite Light. Later in the *Upaniṣads*, Brahman is referred to as the Self-Luminous Light.[d] 'He is the light of lights and the whole world is illuminated with His light.' 'Thousands of Suns pale into nothingness before this Divine Light.'

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[a] Hiriyanna (1), p. 39.
[b] *ṚV.*, I, 113.1.
[c] Aurobindo, pp. 464 ff.
[d] *Muṇḍ. Up.*, II, 20.10.

In consonance with the conception of cosmic light is that of cosmic law, which is known as *ṛta*. The all-pervading light, *Āditya* or *Sūrya*, is extolled as the dweller in eternal (Law) and, eventually, the eternal law itself.[a] *Sūrya* sheds his light according to *ṛta* and he is the face of *ṛta*.[b] *Ṛta* means 'the course of things', order or law which is the primal principle, non-temporal and cohesive. It is a natural law which even the Vedic gods had to follow. Gods are often described in terms of 'guardians of *ṛta*' and 'practisers of *ṛta*'.[c] Figuratively it is stated that 'Gods chant the song of *ṛta*.[d] The natural phenomena, such as the flow of rivers, change of seasons, day and night, are stated to be in accordance with this natural law.[e] Symbolically *ṛta* was also conceived by the Ṛgvedic seers as *Varuṇa* who was supposed to have determined the laws of the physical universe. The *Ṛgveda* says that it is because of *ṛta*, Indra 'lights up and energizes the whole world', and that 'the appearance of *ūṣas* and its illumination of the universe are in conformity with *ṛta*'.[f] In addition, all the phenomena which occur in cycles are stated to be controlled by *ṛta*. In short, *ṛta* is a unitary active principle present everywhere and in everything. As eternal order, it is transcendental signifying uniformity of nature or an ordered course in a cosmic sense. The Ṛgvedic seers were convinced that nature is not heterogeneous as it seems to us, and that all types of natural motions are traceable to *ṛta* which, according to them, is self-existent and ever extending.

Whitehead rightly observes: 'In the first place there can be no living science unless there is a widespread instinctive conviction in the existence of an order of things and in particular of an order of nature.'[g] The Vedic people had the instinctive conviction in the natural order. They thought of the external world as an ordered whole and that its dynamic or changing phenomena were regulated by *ṛta*. In the *Ṛgveda*, therefore, everything is extolled as beautiful and brilliant, for there is no place for chaos and ugliness in the orderly universe. Probably in no other contemporary literature of the Ṛgvedic time was there such a conception of natural law.

Intimately connected with *ṛta* is another monistic principle of the *Ṛgveda*, viz. *yajña* or the act of sacrifice. *Yajña* is referred to as the *navel* of the universe (*viśvanābhi*) round which the latter turns, and as the unifying principle which expands and contracts in accordance with the happenings in the universe. For, the Ṛgvedic seers believed that *yajña* is the instrument for preserving the cycle of cosmic events in harmony. *Yajña* is praised as '*ṛtasya dhāma* and *ṛtasya sadana*' (the abode of *ṛta*).[h] The act of *yajña* is for the protection of *ṛta*. *Yajña* has the connotation of dynamism, too, for it is 'that which expands with the world, and dissolves

[a] ṚV., IV, 40.5.
[b] ṚV., VI, 39.5; 51.1.
[c] ṚV., I, 23.5.
[d] ṚV., I, 147.1.
[e] ṚV., IV, 3.8–12; V, 80.1.
[f] ṚV., III, 61.7.
[g] Whitehaed, p. 4.
[h] ṚV., I, 43.9.

with the world into the creator'. It is thus conceived as a connective dynamic principle in the manifested world, a nucleus (*nābhi*) of all evolution and thus the protector and nourisher of the universe.

Perhaps the highest monistic level was reached by the Vedic thinkers when they thought of a unitary world-ground encompassing the being and the non-being, the living and the non-living. The famous hymn of creation, called the *Nāsadīya Sūkta* in the tenth *Maṇḍala* of the *Ṛgveda*,[a] speaks of *water* as the supra-sensible First Cause or the primeval world-ground; and water is the first 'element' to be conceived in this manner, without any mythological association. 'Then there was neither Aught nor Nought, nor air nor sky beyond; what covered all? Where tested all? In watery gulf profound? ... The ONE breathed calmly, self-contained; nought else beyond it lay. Gloom hid in gloom existed first—One sea, eluding view.'

The foregoing are among the important universal speculations concerning energy (*viśvajyoti*), motion (*ṛtam* and *yajña*) and the primordial stuff of the world (water), appearing in perhaps the most ancient literature of its type in the world. The fact of great significance is that these conceptions were the result of a desire to know the world as a whole—a desire so characteristic of the thinkers of the Vedic period as stated in the following Ṛgvedic *mantra*: 'Give sight to our eyes, sight to our bodies so that they can see. May we see the world as a whole, may we see it in detail.'[b]

THE DOCTRINE OF FIVE ELEMENTS

The universal conceptions, as mentioned above, laid the foundations for newer formulations, again wholistic in nature and structure. One such formulation was the doctrine of five elements to account for the apparently unordered, diverse world of matter and qualities. Known as *Pañcabhūtas* (*mahābhūtāni*), the five elements are: *pṛthvī*, *ap*, *tejas*, *vāyu* and *ākāśa*. These may, for purposes of understanding, be designated respectively as earth, water, fire, air and a non-material uniquitous substance. But it must be noted that the five elements have a wider connotation and significance than the familiar earth, water, fire or air. Moreover the corresponding words in English cannot be deemed as being the proper equivalents. It is, therefore, essential to bear in mind the Sanskrit terms wherever the seemingly corresponding words in English are used to denote them. Further, each element has to be understood in relation to the other four. In other words, the doctrine of five elements should be viewed in its totality.

The fivefold character of the doctrine gradually assumed shape out of simpler conceptions. As stated before, primeval water is the first element in the Indian speculation. Later in the *Bṛhadāraṇyaka Upaniṣad*,[c] it is stated: 'In the beginning this world was just water.' The *Chāndogya*,[d]

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[a] *ṚV.*, X, 129. [b] *ṚV.*, X, 158.4. [c] *Bṛh. Up.*, V, 5.1. [d] *Chānd. Up.*, VII, 10.

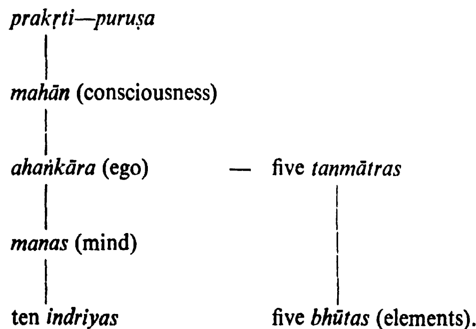
gives an account of the World-stuff as follows: 'It is just water solidified, that is the earth,—the atmosphere,—the sky,—the gods—and men,—beasts and birds,—grass and trees,—animals together with worms,—flies and ants; all these are just water solidified.' In *Kauṣitakī*,[a] it is explicitly stated that 'the waters, verily indeed are my (Brahma's) world'. A clear and evolutionary development of the three elements in this order: water, fire, and *ākāśa*, occurs again in the *Chāndogya Upaniṣad*, in a series of assertions relating to a progressive understanding of Brahman as the Universal Soul which is the main current of the Upaniṣadic thought. The *Chāndogya* also states that 'Brahman, desiring to be *many*, created *tejas* (fire), *ap* (water) and *kṣiti* (earth), and entered into these three'.

Besides, there are a number of passages in the Upaniṣadic literature dealing with the elements step by step towards a unitary conception. The *Taittirīya* states: 'From this Soul (*ātman*), verily, (*ākāśa*) arose; from *ākāśa*, wind (*vāyu*); from wind, fire (*agni*); from fire, water (*ap*); from water, the earth; from the earth, herbs; from herbs, food; from food, semen; from semen, the person (*puruṣa*)'[b] while the *Aitareya* thinks of the five elements in relation to Brahman, the concept of five elements occurs in the *Taittirīya*, *Aitareya* and *Maitrī Upaniṣads*. In the *Maitrī* it is explicitly stated that 'the three-quartered Brahman has its root above, its branches are *ākāśa*, *vāyu*, *tejas*, *ap* and *pṛthvī*'.[c]

The Indian doctrine of five elements, it must be emphasized, is a part of the philosophical ideas. In other words, it does not have an independent standing apart from its being an integrated component of the leading systems of Indian thought. Among the six orthodox systems (so-called because of their acceptance of the Vedic texts) the *Sāṃkhya*, *Nyāya* and the *Vaiśeṣika* have laid special emphasis on the five elements. The Jaina, Bauddha and the Cārvāka schools recognize only the first four elements.

Sāṃkhya

The classical *Sāṃkhya* has the following enumeration:



[a] *Kauṣ. Up.*, I, 7. [b] *Taitt. Up.*, II, 2.1. [c] *Mait. Up.*, III, 1-2; VI, 4.

In this enumeration of totality the five *tanmātras* and the corresponding five elements are of special significance. The *tanmātra* is considered to be invisible and eternal while the corresponding elements, the produced ones, are not eternal. It is rather difficult to define exactly the *tanmātras*. Perhaps they share the characteristics of both mind and matter, and they seem to represent the very core of the element in the finest state, possibly with the inherent power of affecting the respective senses.

The origin of the concept of *tanmātra* can be found in some of the later *Upaniṣads*. In the *Praśna Upaniṣad*,[a] the subtle states are called *pṛthvī-mātra*, *apo-mātra* and the like. The *Maitrī Upaniṣad* mentions the word *tanmātra* in the same context. It can be conjectured that these Upaniṣadic ideas might have influenced the later exponents of the *Sāṃkhya* school to explain the evolution of the gross matter from the primary *tanmātras*.

The generation of the gross matter (in terms of the five elements) out of the *tanmātras* is as follows:[b]

From *śabda* (sound)	*tanmātras*	emerges	*ākāśa*
From *śabda* and *sparśa* (touch)	,,	,,	*vāyu* (air)
From *śabda*, *sparśa* and *rūpa* (colour)	,,	,,	*tejas* (light)
From *śabda*, *sparśa*, *rūpa* and *rasa* (taste)	,,	,,	*ap* (water)
From *śabda*, *sparśa*, *rūpa*, *rasa* and *gandha* (odour)	,,	,,	*pṛthvī* (earth)

The elements have the following attributes: *ākāśa* (sound); *vāyu* (sound and touch); *tejas* (sound, touch and odour); *ap* (sound, touch, colour and taste); and *pṛthvī* (sound, touch, colour, taste and odour). There are two noteworthy aspects in this scheme: (i) the attributes are based upon the five senses; and (ii) the five elements are thought of in relation to these attributes. This integrated concept, therefore, includes the sensorial and the gross. The subtle are the *tanmātras* which have potential power of affecting the sense and the gross are the five elements corresponding to the five senses. The subtle ones, presumably, have been conceived as the ground for the five gross forms.

According to the *Sāṃkhya*, all gross things are formed by the grouping and regrouping of the five elements. The noticeable differences among substances are due to the different types of collocations or groupings. It may be noted that the *Sāṃkhya* holds that there can be no production of a thing which is non-existent previously, in tune with its theory of causation known as the *satkāryavāda*. In this view, the production means a change in the arrangement and that which is potentially present or the unmanifest becomes manifest—a sort of a 'continual transformation (*pariṇāma*)'. The five elements play their role in this transformation.

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[a] *Praś. Up.*, IV, 8.

[b] *SK.*, 38.

The *Sāṃkhya* doctrine of the five elements did influence a great deal in the development of certain concepts of the *Āyurveda*, the principal Indian medical system. For, the *Āyurveda* has adopted the principles of *Sāṃkhya* with certain modifications, bestowing special importance on the five elements and their role even in the physiological processes.[a]

According to the *Āyurveda*, the world consisting of the inorganic as well as the organic is formed out of the five elements. Even the substances which are used as medicines are, as a rule, composed of five elements. The *indriya* or the sensory organ has in it the five elements; only the particular *indriya* will have one element in greater proportion and the other four in relatively smaller proportions. The human body is considered as a combination of the five elements and soul.

In the *Suśruta Saṃhitā*[b] there is a clear exposition of the way in which the five elements constitute a human body from its very conception. The embryo which has in it the energetic principles is separated into form by *vāyu*. The *tejas* transforms the embryo. The *ap bhūta* maintains its moist structure, while the *pṛthvī* tries to give shape and size to it, and keep it intact by contributing hardness to it. *Ākāśa* offers expanse to the embryo and develops it. Thus comes into play the body or *śarīra* on account of the five elements.

The *Āyurveda* recognizes five types of substances, viz. *ākāśīyadravya*, *vāyavīyadravya*, *taijasadravya*, *āpyadravya* and *pārthivadravya*.[c] It should be emphasized that, according to the Āyurvedic concept, each of the five types of gross bodies contains the particular element in greater proportion while the other four are also present in it, of course, in minute but different proportions.

The five elements are also associated with the formation of the six *rasas*, viz. *madhura* (*pṛthvī*+*ap*); *amla* (*tejas*+*pṛthvī*); *lavaṇa* (*ap*+*tejas*); *tikta* (*ākāśa*+*vāyu*); *kaṭu* (*tejas*+*vāyu*); and *kaṣāya* (*pṛthvī*+*vāyu*).[d] Yet it should not be understood that the corresponding two elements alone constitute a particular *rasa*; only these two are predominant in it while the other three would also enter into its composition. Thus is maintained the wholistic nature of the doctrine of five elements.

The *Sāṃkhya* enumeration of the five elements should be viewed in the light of the *Sāṃkhya* thought-structure itself. For, according to the *Sāṃkhya*, the material universe emanates out of *prakṛti* which is conceived to be the 'rootless root of the universe'. It is believed to be unmanifest and in a state of equilibrium with respect to the three *guṇas*, viz. *sattva*, *rajaṣ* and *tamas*. Thus, *prakṛti*, though single, is complex. As a result of interaction of *puruṣa*, *prakṛti* is imagined to unfold or evolve itself. In this process, matter first in the subtile form and later in the gross form, owes its origin to the three *guṇas*. The *guṇas* are the constituent principles of the universe, and matter is an offshoot of the intermingling of these three

[a] *SS. Śā.*, **1**, 4–6.
[b] *SS. Śā.*, **5**, 2.
[c] *SS. Sū.*, **41**, 3–7.
[d] *SS. Sū.*, **42**, 3.

guṇas. The five elements are even recognized in terms of the three *guṇas* in different combinations. The *guṇas*, however, are not the qualities of *prakṛti*, nor of the elements. They are abstractions bordering on the conception of substance. *Sattva* is that which is light and fine, *rajas* that which is active, and *tamas* that which is gross and heavy. These postulations obviously are intended to account for the whole variety of the universe as the substratum of change. In this process of change the *guṇas* persist, only their modes become potent. It would appear that the *Sāṃkhya* believes in the indestructibility of matter and in the continual operation of force in terms of the modes of the perpetually active *guṇas*.

THE *VAIŚEṢIKA* AND THE *NYĀYA*

The *Vaiśeṣika* and the *Nyāya* systems have their own assessment of the five elements. They have given a concise and clear account of each of the five elements as follows:

Pṛthvī (earth)

It is of two kinds: eternal and evanescent, eternal in the form of atoms and evanescent in the form of products. The latter comprise many substances which are commonly perceived. The special quality of earth is odour. The earthy products are threefold: (i) in the form of body; (ii) the sense organ (olfactory); and (iii) objects of perception. The objects include rocks, minerals, various kinds of stones, gems, diamond, etc. on the one hand and vegetables, grasses, herbs, trees with their flowers and fruits, and other types of plants. Earth possesses fourteen qualities: colour, taste, odour, touch, number, dimension, distinctness, conjunction, disjunction, distance, proximity, gravity, fluidity and faculty.[a]

Ap (water)

Like earth, water is also of two kinds: eternal and non-eternal. It is eternal in the form of atoms and non-eternal as products. Its products are again threefold: (i) body; (ii) sense organ; and the (iii) object. The body is in the region of Varuṇa. The sense organ is that of taste. The objects exist as rivers, oceans, hails, moon and the like. The special quality of water is taste. Its colour is white. It has also fourteen qualities: colour, taste, touch, number, dimension, distinctness, conjunction, disjunction, distance, proximity, gravity, viscidity, fluidity and faculty.[b]

Tejas (fire)

Fire, regarded as white and brilliant, is of two kinds: eternal (atoms) and non-eternal (products). The products are also threefold: (i) body (which belongs to the region of the sun); (ii) sense organ (visual); and

[a] *PBh.*, pp. 70–71.

[b] *PBh.*, pp. 90–91.

(iii) objects which are of four types: earthly, heavenly, stomachic and mineral. The earthly fire is that which is perceived ordinarily, such as wooden fire. The heavenly is the one observed as sun, lightning and the like. The stomachic fire is that which brings about the digestion of food. The mineral fire exists in the form of gold and other metals. Fire has colour as its special quality. It has in all eleven qualities: colour, touch, number, dimension, distinctness, conjunction, distance, disjunction, proximity, fluidity and faculty.[a]

Vāyu (air)

Air is also eternal (in the shape of atoms) and non-eternal (as products). The products are of four types: (i) body, existing in the region of the *Maruts* (atmospheric); (ii) sense organ, pervading all over the body (tactile); (iii) object (that which is actually perceived as air and is the substratum of tactile sensation); and (iv) breath (air in the body which moves various fluids and secretions on account of its distinct functions). The qualities of air are touch, number, dimension, distinctness, conjunction, disjunction, proximity, distance and faculty. Air has motion and the motion is transversal (*tiryak*). It enables the clouds to keep at rest and also moves them from place to place. It also causes the showering of rains and does not let the weighty substances fall to the ground.[b]

Ākāśa

While earth, water, fire and air are considered material, the fifth element, *ākāśa*, is regarded as non-material, one and all-pervading. Its special quality is sound. The auditory organ is of *ākāśa* itself. Its general qualities are: sound, number, dimension, distinctness, conjunction and disjunction.[c]

It will be seen from the foregoing enumeration that all the knowable or sensorial objects are categorized with reference to these five elements. In fact, they are generic names signifying the respective atomic states, gross matter, senses, the different forms and even attributes. It is interesting to note that in the *Nyāya-Vaiśeṣika* classification of the five elements, there is a significant relation between the elements and the senses. The visual, gustatory, olfactory, tactual and auditory organs are respectively made of fire, water, earth, air and *ākāśa*. The principle governing this relation seems to be one of 'like apprehending like'. The eye apprehends colour and colour is the specific attribute of fire element; hence eye must have in it the fire element. Likewise tongue apprehends taste and taste is the specific attribute of water; hence the element composing the tongue is water and so on. However, the principle of 'like apprehending like' seems to find its limitation with reference to the internal organ, namely *manas*. Though *manas* experiences qualities such as pleasure and pain,

[a] *PBh.*, pp. 97–99. [b] *PBh.*, pp. 111–13. [c] *PBh.*, pp. 143–44.

it is not made of any substance which possesses these qualities. The role of *manas* as a substance is discussed later.

Of great importance is the fact that the *Nyāya-Vaiśeṣika* view of the five elements is a part of its concept of what is designated as *dravya* (substance). Substance is the first of the six categories. The other five are *guṇa* (attribute), *karma* (action), *sāmānya* (generality), *viśeṣa* (particularity) and *samavāya* (inherence).[a] These six categories, it is emphasized, are not subjective notions, nor are they necessities of thought. In the *Nyāya-Vaiśeṣika* scheme they are the reals, and a knowledge of them is the knowledge of reality.

Substance is considered to be the most important, as it is the substratum (*āśraya*) for the others. It is of nine types: (i) *pṛthvī* (earth); (ii) *ap* (water); (iii) *tejas* (fire); (iv) *vāyu* (air); (v) *ākāśa*; (vi) *diś* (space); (vii) *kāla* (time); (viii) *ātmā* (self); and *manas* (mind).[b] The salient features of the *Nyāya-Vaiśeṣika* conception of *substance* is shown on the following page. In this plural presentation, the finite and material (*pṛthvī*, *ap*, *tejas* and *vāyu*), the non-material and the ubiquitous (*ākāśa*, *diś* and *kāla*), and the conscious self (*ātmā*) as well as mind (*manas*) have been integrated in a rational way. The self is a generic title and includes the individual selves. It possesses all-pervasive character and hence has the highest dimension without any motion. Mind, the internal organ, is capable of bringing about cognition, pleasure, pain and the like. It aids self, of course, with the help of the sense organs. Mind is considered to be atomic without any specific quality and is believed to possess motion as it cognizes objects instantaneously. Both self and mind are essential for experience—one having consciousness and the notion of 'I', the other not having consciousness, yet nourishing the notion of 'I'.

The foregoing nine substances of the *Nyāya-Vaiśeṣika* focus an integrated view on the world-stuff or substance in an ingenious way. It will be observed that this conception of substance is inclusive of the attributes also. For, it is stated that the attributes cannot exist apart from the substance; they inhere in the latter. Yet the substance is not identical with or togetherness of its qualities. In this respect the *Nyāya-Vaiśeṣika* differs from the *Sāṃkhya* and also the Buddhist view on matter.

ATOMISM

One of the most noteworthy Indian physical concepts is atomism. Perhaps it may not be proper to consider this concept chemical or physico-chemical for the reason that the Indian atomism is one of speculation, based on causal consideration. When the atoms, the primordial stuff of the world, unite to form the gross bodies, the process seems to be a physical one strictly following a plausible causal mechanism. In this manner the *Nyāya-Vaiśeṣika*, the Jaina and the Bauddha schools have expounded

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[a] *VS.*, 1, 1.7.

[b] *VS.*, 1, 1.4.

TABLE

Different types of substances and their attributes

pṛthvī	*ap*	*tejas*	*vāyu*	*ākāśa*	*kāla*	*diś*	*ātman*	*manas*
eternal in atomic state	eternal in atomic state	eternal in atomic state	eternal in atomic state	eternal and one	eternal and one	eternal and one	eternal and plural	eternal and plural
corporeal	corporeal	corporeal	corporeal	ubiquitous	ubiquitous	ubiquitous	ubiquitous	corporeal
principle of olfactory organ	principle of gustatory organ	principle of visual organ	principle of tactile organ	principle of auditory organ (limited by the air-hole)	–	–	–	–
specific quality—odour	specific quality—taste	specific quality—colour	specific quality—touch	specific quality—sound	–	–	–	–
14 qualities: colour, taste, odour, touch, number, dimension, distinctness, conjunction, disjunction, distance, proximity, gravity, fluidity and faculty	14 qualities: colour, taste, touch, number, distinctness, dimension, conjunction, disjunction, distance, proximity, gravity, viscidity, fluidity and faculty	11 qualities: colour, touch, number, dimension, distinctness, conjunction, disjunction, distance, proximity, fluidity and faculty	9 qualities: touch, number, dimension, distinctness, conjunction, disjunction, proximity, distance and faculty	6 qualities: sound, number, dimension, distinctness, conjunction and disjunction	5 qualities: number, dimension, distinctness, conjunction and disjunction	5 qualities: number, dimension, distinctness, conjunction and disjunction	14 qualities: cognition, pleasure, pain, desire, aversion, effort, virtue, vice, faculty, number, dimension, distinctness, conjunction and disjunction	8 qualities: number, dimension, distinctness, conjunction, disjunction, priority, posteriority and faculty

(The five generic qualities: number, dimension, distinctness, conjunction and disjunction common to all the substances)

their atomic concepts. The word used for atom is *aṇu* or *paramāṇu*. Each school has conceived of *aṇu* or *paramāṇu* as a logical necessity to explain the physical world in furtherance of its own philosophical ideas.

THE *NYĀYA-VAIŚEṢIKA* ATOMISM

The *Vaiśeṣika*, *Nyāya* and the later syncretic *Nyāya-Vaiśeṣika* exponents are noted for their logically-structured atomism.[a, b, c] The concept of *avayavin* (whole) and *avayava* (constituent part) has shaped the atomic theory of the *Nyāya-Vaiśeṣika*. As stated before, the substance is considered to be of nine types. Among them, the first four, viz. earth, water, fire and air, are considered to be atomic. The atom is indestructible (i.e. eternal), indivisible and without any magnitude. Each element has its own class of atoms with particular attributes. However, all the atoms are regarded as spherical. The four kinds of atoms possess specific attributes as follows: earthy atom has odour, airy atom—touch, watery atom—taste, and fiery atom—colour. By these particular attributes the atoms are capable of being differentiated, i.e. qualitatively.

Constructively, it is the atoms that produce matter of visible magnitude. The process is logically thought of as follows. According to the *Nyāya-Vaiśeṣika*, atoms are in eternal motion. As a result, there always exists a possibility of combination of any two like atoms, i.e. atoms of the same physical substance. It is, however, presumed that the combination takes place in the presence of atoms of the other substance or substances also. The two like atoms are the material causes for the combination while the other types of atoms are considered to play the role of supportive atoms. Two unlike atoms, i.e. an atom of earth and an atom of water cannot, it is stated, enter into combination.

The effect of the combination of the two like atoms goes by the name of dyad (*dvyaṇuka*).[d] The dyad is also suprasensible as well as infinitesimal even though it is formed out of two atoms. The magnitude of the dyad is stated to be derived from the number *two* only. The question is: Why is it that only two atoms combine to begin with? Atom is so minute that it cannot be a causative component in such a way that it contributes to the magnitude of the product. Minuteness, in other words, cannot contribute to grossness. The atomic magnitude is of the minutest order. Consequently it can only impart a magnitude which would still be in the same order of minuteness. This means that the magnitude of a dyad is not superior to that of the two atoms which produce the former. Hence the conclusion that the magnitude of a dyad must be derived from the number of atoms only. Logically the minimum number of atoms that can be causative is two and hence the first product is a dyad.

In the atomism of the *Nyāya-Vaiśeṣika*, the dyad, as stated before, is not considered as gross matter. In other words, it is invisible. The minimum

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[a] Bhaduri, pp. 55–81.
[b] Mishra (U.) (1), pp. 64–159.
[c] Keith (4), pp. 10–17.
[d] Mishra (U.) (1), pp. 116–17.

visible is a triad, designated as *trasareṇu* or *tryaṇuka*[a] (of the size of a mote in sunbeam). A triad is formed out of three dyads. Nevertheless, the triad is not formed directly from six atoms which constitute the three dyads which are recognized as the intermediates between the primordial atoms and the triad. The atoms as well as the dyads are considered as not having any extension in themselves. In addition, they do not possess magnitude on a gross scale. These two concepts mean then that the gross magnitude of the triads is not due to atoms or the inter-dyadic space, but is due to the plurality of dyads. The minimum standard for plurality is again logically three. Hence at least three dyads are required for the production of the minimum gross matter. Dyads numbering more than three can also enter into union. For example, four dyads can combine to form a product, a tetrad.

As stated earlier, the atoms (six or eight in number) cannot directly form a triad or tetrad (*caturaṇuka*) as the case may be. For, it is argued by the *Nyāya-Vaiśeṣika* that a thing of gross magnitude is formed by those which are themselves products. Atoms are eternal, and if they were to produce a gross substance like a triad directly, the process would go on and the resultant would also be eternal. But the experience is to the contrary. This anomaly can therefore be overcome by postulating that the dyads, which are the products of atoms and which are neither eternal nor indestructible, constitute the triad, tetrad and so on. Thus atoms play only one role, i.e. the production of a dyad. They do not have yet another role to play, i.e. to produce in addition a triad directly.

The atomism of the *Nyāya-Vaiśeṣika* is noted for its strict adherence to the principle of causality. Atoms are the material cause for a dyad, the effect; the dyads are the cause for the production of a triad which is again an effect. The atoms lose their causal efficiency after the triad comes into existence. In this way, the chain of formation of gross bodies can be maintained. The cause in each case brings about the effect, but is immediately absorbed into the latter which in turn performs the functions of a cause to continue the sequence. In dyads the two like atoms do exist; only they are devoid of their causative functions. In other words, their activities as atoms are exhausted.

Further the *Nyāya-Vaiśeṣika* atomism has a rational explanation for the presence of different qualities in a single substance. A triad of earth possesses various qualities because of the presence of different types of atoms, say of fire or water. Besides, the structural arrangement (*vyūha*) of a triad, it is said, confers the observed properties on the substance.

Why do the primordial atoms unite and produce gross matter? The explanation given by the *Vaiśeṣika* is that there is what may be designated as the unseen (*adṛṣṭa*) which sets off this process. *Adṛṣṭa* as an unseen force, then, is the efficient cause of the world while atoms are its material cause.

It is now fairly certain that the atomic views of the *Vaiśeṣika* school were in existence even in the pre-Buddhist period. In course of time the

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[a] Mishra (U.) (1), pp. 114–16.

Vaiśeṣika atomism was developed by a number of its adherents. Among them Praśastapāda, Udyotakara, Vācaspati Miśra, Udayaṇa, Śrīdhara, Jayantabhaṭṭa, Śaṅkara Miśra and Raghunātha Śiromaṇi threw fresh light on this mode of thinking. The atomism had its powerful opponents, too. The great Śaṅkarācārya (*c.* eighth century A.D.) opposed the atomic views in unequivocal terms. Yet even in the late middle ages the atomism was very popular among the learned and continued to enjoy a considerable following. Even the followers of the *Pūrva-Mīmāṃsā* school, like Prabhākara (probably late seventh century A.D.) and Kumārila (*c.* eighth century A.D.), subscribed to the atomic theory of the *Nyāya-Vaiśeṣika*. In fact, Prabhākara introduced the problem of part and whole (*avayava-avayavī*) and recognized atoms as the material cause. In the history of science the *Vaiśeṣika* atomism seems to have gone almost unnoticed while the Greek atomism of Leucippus and Democritus (about fifth century B.C.) has earned its due position.

The Nyāya-Vaiśeṣika and Greek Atomic Views

The *Vaiśeṣika* atomism differs from the Greek atomism in conception as well as formal details. In the Greek atomism, both atoms and void are real. The atoms have different sizes and shapes, and they constitute the physically indivisible building materials of the universe. Moreover, the atoms are held to be in perpetual motion; and thus motion and void are equally real. This idea is not found in the *Nyāya-Vaiśeṣika* atomism. While the atoms of the Greeks have quantitative differences, those of the *Vaiśeṣika* are noted for their qualitative differences. As mentioned already, there are four classes of atoms corresponding to earth, fire, water, and air, each class of atoms having different specific qualities. Furthermore, while Democritus considers that atoms are in eternal motion, the *Vaiśeṣika* believes that they are not in such a state of motion. Only the free atoms at the time of creation are recognized to be in motion. Above all, Democritus thinks of soul to be composed of atoms and seeks to explain the life processes in terms of atoms. The *Nyāya-Vaiśeṣika*, on the other hand, regards soul to be non-material and hence not being composed of atoms. The non-material conscious soul is not explained in terms of material unconscious atoms. Besides, there is in Greek atomism a sort of mechanical conception of the universe, while such a view is totally absent in the *Nyāya-Vaiśeṣika* atomism. The *Vaiśeṣika* concepts of *adṛṣṭa*, *ākāśa*, atomic dimension, dyad, triad and the like do not have their parallels in the Greek atomic views.[a]

Now a question arises: historically is the atomism of the *Vaiśeṣika* earlier than that of the Greeks? As mentioned earlier, the *Vaiśeṣika* school is pre-Buddhistic.[b] It is reasonable to suppose, therefore, that the *Vaiśeṣika* atomism has its claims for antiquity. But it is very difficult to

[a] Subbarayappa (1), p. 127.

[b] Kuppuswamy Sastry, p. xviii.

say how far the Greeks were influenced by the Indian atomism against their philosophical convictions. All that can be said with a fair degree of certainty, based on the available evidence, is that the concept of atom is a product of an intuitive mind imbued with a spirit of free inquiry. The Indian and the Greek thinkers were intuitive and indulged in free inquiry. Therefore, the two atomisms might have originated independently of each other.

The Jaina Atomism

The two heterodox systems, the Jaina and the Bauddha, have developed also an atomism, each in its own way and structurally different from that of the *Nyāya-Vaiśeṣika*. The Jaina thinkers discard the doctrine of part-whole of the *Nyāya-Vaiśeṣika*. In addition, they maintain that atom is both cause and effect—a view totally at variance with that of the *Nyāya-Vaiśeṣika*. For, the latter asserts unequivocally that atoms are the material cause of the world. In the Jaina view, the world is not merely a changing phenomena but is beginningless and endless. It is said to be composed of two principal categories: *jīva* (the living) and *ajīva* (the non-living). The latter comprises *dharma*, *adharma*, *ākāśa*, *pudgala* and *kāla*. Each of them (except *kāla*) is known as *astikāya*, i.e. that which exists and has pervasiveness, and occupies space or *pradeśa*. A *pradeśa* is part of *ākāśa* occupied by the ultimate particle called *aṇu* or *paramāṇu* (atom). The *Bhagavatīsūtra* defines *paramāṇu* as that which cannot be cut or divided.[a] The atom is also conceived to be the subtlest particle, without any parts, even though with reference to its *bhāva* (condition) its capacity is said to change in relation to colour, taste, smell and touch. The Jaina atom appears also to be in the nature of a point with reference to *kṣetra* or field, and momentary with reference to *kāla* or time.

Pudgala is that which undergoes transformations by combinations (*pud* = to combine) and dissociations (*gala* = to dissociate). It is said to possess five kinds of colour (black, blue, red, yellow and white), eight types of touch (soft, hard, heavy, light, cold, hot, smooth and rough), five tastes (bitter, pungent, acidic, sweet and astringent) and two different odours (fragrance and its opposite).[b] According to Kundakundācārya, *pudgala* is that which can be experienced by the five senses and has forms or states. The two recognized states of *pudgala* are atomic (*aṇu*) and aggregate (*skandha*). Amṛtacandasūri recognizes six kinds of modifications of *pudgala*, viz. *bādara-bādarāh*, *bādarāḥ*, *bādara-sūkṣma*, *sūkṣmabādara*, *sūkṣma* and *sūkṣma-sūkṣma*.[c]

The Jaina thinkers believe that two or more atoms combine to produce an aggregate. The latter is called *skandha*, and the physical world is a *mahāskandha*. A *skandha* may contain two or more atoms. It may also be formed by the dissociation of large *skandhas*. While the atom is abso-

[a] *Bhag. Sū.*, **20**, 5.570. [b] Mishra (U.) (2), I, p. 317. [c] Mishra (U.) (2), I, pp. 317–20.

lute and without beginning, the *skandha* is not absolute and beginningless. Two *aṇus* produce a *dvipradeśa* (a *skandha*). Similarly a *tripradeśa skandha*, *caturpradeśa skandha* and so forth are thought of. According to the Jainas there are also *skandhas* with countable units (*saṃhatapradeśika*), uncountable units (*asaṃkhyātapradeśika*), infinite units and in finite-fold combinations. Further, with reference to vibration and non-vibration, there are varieties of *skandhas* according as the component atoms vibrate, non-vibrate, partly vibrate and partly non-vibrate.

The atoms combine because of their inherent attributes, viz. *snigdha* (attractive force), *rūkṣa* (repulsive force) and even *snigdhatva-rūkṣatva* (attractive-*cum*-repulsive force). These two attributes are natural to or inherent in the atoms as well as the *skandhas*. This is in contradistinction to the concept of *adṛṣṭa* of the *Nyāya-Vaiśeṣika*. According to Umāsvātī,[a] combination of similar or dissimilar atoms occurs when there is a difference of at least two units of *snigdha* or *rūkṣa*. In other words, the atoms cannot combine if they do not have sufficient degree of *snigdha* or *rūkṣa*; nor would they combine when they are of equal degree. Likewise, two similar types of atoms (say, those which have cohesive forces) cannot enter into combination. In a refreshing approach, the Jaina appears to hold the view that a combination means the coming into play of the cohesive and repulsive forces which are natural to the atoms.

Further, each atom is said to possess the attributes (*bhāvas*) of touch, taste, odour and colour, even so potentially; for *pudgala*, composed as it is of atoms, possesses these attributes. According to the Jaina view, these four qualities associated as they are with what is called *vyavahāra paramāṇu* in contradistinction to the indivisible *sūkṣma paramāṇu*, are also capable of being divided. While the atoms of the *Nyāya-Vaiśeṣika* differ from one another qualitatively, the Jaina atoms are all similar without any qualitative or quantitative differences. In short, they are of one class without any distinction such as, earth-atom, water-atom, etc., like those of the *Nyāya-Vaiśeṣika*. Thus every atom is capable of producing any colour, odour, taste and touch. However, it is believed that, in relation to the attribute of a *skandha*, the corresponding atoms may have attributes also.

The atom, according to the *Bhagavatīsūtra*,[b] is endowed with one colour (black, blue, red, yellow or white), one taste (bitter, sour. astringent, acidic or sweet), one smell (pleasant or unpleasant) and two touches (cold and cohesive, warm and cohesive, cold and dry or warm and dry). However, the atom is not considered to be heavy or large, but light (*agurulaghu*) in its own state. There is no matter lighter than atom.[c] The attributes are present in every atom to an equal extent, participating in transformations and aggregations. It is of interest to note that the Jaina thinkers do not regard the aggregate (*skandha*) as a new substance, but as a special form of the aggregation of atoms which are infinite in number. A noteworthy

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[a] *TSū. Bh.*, **5**, 23. [b] *Bhag. Sū.*, **20**, 5.668. [c] *Bhag. Sū.*, **25**, 4.740.

aspect of the transformation is that, as atoms are devoid of shape, no transformation with reference to shape is possible. Evidently the atoms experience increase or decrease in their attributes. There could be infinite groups of transformations even though there are admittedly (5×5×2×4) two hundred basic such groups.[a] In the Jaina view the atom is not always active. It sometimes vibrates or revolves itself in a regular (*samita*) or irregular (*aniyamita*) way. The motion of atom when it proceeds from one point of space to another is considered to take place in a straight line. Some of the Jaina texts like the *Bhagavatīsūtra*, *Pannavana* and *Sthānāṅga sūtra* discuss in considerable detail the vibration of the atom from the point of view of time, its dissociation from *skandha*, resistance encountered in its activity and the like.

It would appear that the Jaina concept of *pudgala* and of atoms is a well-knit part of the religious speculation; for, the Jaina believes that *karma* is also composed of subtle particles of matter and that these particles find their path into the soul which, as a result, becomes corrupt. *Jīva* is believed to take in such *pudgalas* as are productive of *karma*. And Jaina thinkers have given an elaborate account of how the *karmapudgalas* flow into *jīva* and how soul and atom can exist together in one space-point. It is even pointed out that wherever there is an atom, there are one unit of *dharmāstikāya* and one unit of *adharmāstikāya*. In understanding the Jaina atomism these aspects have to be kept in view.

The most important aspect of the Jaina view of matter, however, is that matter exists eternally and does not remain in the atomic state as if to signify the beginning or to mark the end. This means, then, that the Jaina atoms represent a stage in the natural process. In other words, they are not the ultimates of gross matter. The Jaina atom, in addition, is a determinant of the period of time according as it experiences motion from one point in *ākāśa* to the immediate next point.

The Bauddha Atomism

There does not seem to be any account of atomism in the old canonical Buddhist works. The four principal Buddhist schools are: *Vaibhāṣika* and *Sautrāntika* (belonging to the *Hīnayāna sect*), the *Yogācāra* and the *Mādhyamikā* (belonging to the *Mahāyāna sect*). The *Mādhyamikā* school does not subscribe to the reality of matter. The *Yogācāra* also declares that the external world is not real. Hence both these schools are opposed to the atomic theory of matter. The *Vaibhāṣika* and the *Sautrāntika* which are regarded as the realists (*sarvāstitvavādins*) admit the atomic state of matter within their philosophical views. They have elaborated on atomic view of matter as a part of their concept of *rūpa*.[b] They consider matter as collocation consisting of the fourfold substratum of colour, taste, odour and touch, and regard atom as the minutest unit of *rūpa* (that which has the capacity to affect sense organs).

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[a] *Bhag. Sū.*, **1**, 9.73; **25**, 4.730.

[b] Das Gupta, I, pp. 94–95; 121 ff.

According to these Buddhists, the atom is 'indivisible, unanalysable, invisible, inaudible, untestable and intangible'. However the Bauddha atoms are momentary in the sense they undergo phase-changes continually. There are two types of atoms: simple (*dravyaparamāṇu*) and compound (*saṃghātaparamāṇu*). Nevertheless, some different views have been expressed concerning their aggregation. Some believe that it is a clean combination; others think that there remains always an intervening space between the atoms; and yet others view that they are in such a close proximity that there is no inter-atomic space. In the ultimate analysis, it would seem that the Bauddhas do not think of a combination of the modern chemical type between the atoms. By and large, they appear to hold the view that gross matter is a conglomeration of independent atoms (a sort of a cluster having one atom at the centre and the others around it), and that the latter are not hollow and hence cannot penetrate one another.

According to the Buddhists, there are in an aggregate eight atoms—four fundamental and four secondary atoms. The fundamental ones are of earth (solid), water (liquid), fire (hot) and air (moving). The secondary atoms are of colour, odour, taste and touch. Thus in this scheme the qualities are also atomic. Moreover the Buddhists seem to regard organs of sense as modifications of atomic matter. Each secondary atom requires four fundamental atoms for its support. The aggregate therefore consists of 20 atoms ($4 \times 4+4$) if the body does not sound. If it is to sound, the aggregate will consist of 25 atoms.[a]

The Buddhists do not speak of atoms in terms of particles of some stuff; instead they think of them as force or energy thus: earthly atom-force of repulsion; watery atom-kinetic energy.[b] All these forces are considered to be present in all things and in the same proportion. Different types of bodies (say liquid or solid) are perceived because the intensity of the force-content of the different elements varies, even though the proportionality of the elements remains unaltered. The Buddhist view of atoms as dynamic forces is in tune also with the doctrine of momentariness which unequivocally states that all things change and everything is momentary. ('All things without exception are nothing but strings of momentary events'). The so-called permanence or stable existence of objects which are perceived in the ordinary way is indeed a function of our thought-process. What is ultimately real is instantaneous being. As things have momentary existence, i.e. as they disappear as soon as they appear, the Buddhists do not consider motion with reference to matter at all. But, as Śāntirakṣita says, 'The essence of reality is motion. Reality is indeed kinetic... the interdependence of the moments following one another, evokes the illusion of stability of duration, but they are forces (*saṃskāras*) flashing into existence without any real enduring substance in them... An everlasting substantial matter is pure imagination'. The atomism of the Buddhists should be viewed in this light also.

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[a] Stcherbatsky, I, pp. 190 ff.

[b] Stcherbatsky, I, p. 191.

ATTRIBUTES OF MATTER

Of all the systems of Indian thought, the *Nyāya-Vaiśeṣika* has laid considerable emphasis on the attributes of matter. The *Nyāya-Vaiśeṣika* holds that the qualities or attributes do not have separate existence, but reside in the substances. Each substance is a substratum for certain attributes. The *Vaiśeṣika sūtra* mentions seventeen such attributes. Later its celebrated exponent, Praśastapāda, has added seven more. As a result, twenty-four attributes are enumerated. These attributes are: colour, taste, odour, touch, number, dimension, distinctness, conjunction, disjunction, priority, volition, virtue, vice, gravity, fluidity, posteriority, intellect, pleasure, pain, desire, aversion, viscidity, faculty and sound.[a]

Each of the nine substances has a number of attributes from among the aforementioned twenty-four. Those of the first five substances, viz. earth, water, fire, air and *ākāśa*, have been mentioned already. The attributes of the other four substances are as follows: *kāla* (time; 5 qualities): number, dimension, distinctness, conjunction and disjunction; *diś* (space; 5 qualities): number, dimension, distinctness, conjunction and disjunction; *ātmā* (self; 14 qualities): cognition, pleasure, pain, desire, aversion, effort, virtue, vice, faculty, number, dimension, distinctness, conjunction and disjunction, and *manas* (mind; 8 qualities): number, dimension, distinctness, conjunction, disjunction, priority, posteriority and faculty.

Again the specific attributes, viz. sound, touch, taste and smell, are perceived by the respective sense organs: There are five general qualities: number, dimension, distinctness, conjunction and disjunction which are possessed by every substance. Among the twenty-four qualities some are physical in nature while a few belong to the realm of mind and the notion of 'I'. Some of the important physical qualities are briefly set out below:

Gurutva (*gravity*)

The *Nyāya-Vaiśeṣika* holds that gravity is the cause of falling[b] when there is no conjunction or self-reproduction of motion. Though imperceptible, gravity can be inferred from the action of falling. The falling of rain water is considered to be due to gravity. The *Vaiśeṣika* thinks that gravity resides in the object as a whole and not in its parts. The body of a man does not fall because gravity is said to be counteracted by the effort of the man to keep standing. An object placed high up does not fall because of its conjunction with its support. The arrow which is shot out in air does not fall to the ground because of the impetus it possesses, and the impetus neutralizes the effect of gravity. The theory of impetus of the *Vaiśeṣika* has been discussed later. Gravity is supposed to be eternal as well as temporary. The gravity of the atoms of earth as well as of water is considered eternal, while the gravity of the products

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[a] *PBh.*, p. 229.

[b] *PBh.*, p. 640.

or of the gross bodies is regarded as evanescent, i.e. the latter is destroyed by the destruction of its substratum.

From the foregoing it would appear that the *Vaiśeṣika* regards gravity not as a force, but as a qualitative causal factor with the act of falling as its effect. Though the word *gurutva* has the connotation of heaviness or weight, there seems to be no correlation between gravity and the mass of the substance. Among the substances only earth and water are supposed to possess gravity. In other words, gravity is not considered as a property of all ponderable substances.

Dravatva (fluidity)

Fluidity is considered to be the quality of the three corporal substances—earth, water and fire. It is the cause of the action of flowing in the same way as gravity is the cause of the act of falling. Fluidity is of two types: natural and incidental. The former is the specific property of water. Even so water is said to lose this quality on becoming a solid in the form of snow or hail. There is even a view that the fluidity of watery atoms is brought about by some external agency like subtle supernatural fire. Strangely, salt is considered to be aqueous in nature because in course of time it 'melts into an aqueous form' (possibly referring to the property of deliquescence due to the presence of magnesium chloride in common salt). Likewise, fire is also regarded as a substance possessing the quality of fluidity, for fluidity of melted butter or gold is caused by fire.[a]

Snigdha (viscidity)

As a specific quality of water, viscosity or viscidity is the cause of cohesion and smoothness. As a result of this quality, agglutination or a holding together of particles (*piṇḍibhāva*) occurs in the form of a lump. In other words, viscidity counteracts any tendency of the particles to disperse. Thus it is an operative cause of conjunction against a possible tendency of disjunction. Water is said to possess this property because the particles of earth or flour, for example, are agglutinated in contact with it to form a dough.[b]

Sthitisthāpaka (elasticity)

Elasticity is a particular kind of the attribute, *saṃskāra* (faculty). It is a quality of only the earthy substances which have their component-particles packed together. It is this property that is responsible for a bow, a thread or a branch of a tree which can undergo contraction or expansion. It would appear that elasticity is thought of as a cause or force bringing about a come-back to the original condition in an object which has already experienced the opposite state.[c]

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[a] *PBh.*, p. 641.
[b] *PBh.*, p. 645.
[c] *PBh.*, pp. 697–712.

Saṃyoga and Viyoga or Vibhāga (conjunction and disjunction)

As stated already, these two attributes belong to all the nine substances. Conjunction denotes the 'joining together' of two substances already lying apart. It may be a result of the action of one or both the objects. In the former case, an active object, say a flying bird, comes in contact with an inactive one, say a tree or hill. In the latter case, there is collision of two things moving in opposite directions. Conjunction thus means that there is no intervening space between the two objects. In addition, it connotes that there is non-separate existence of two individual substances. What is more, it is an event in time. Pressure and impact are also thought of as two special kinds of conjunction. Pressure is a type of contact of a body with another; it produces a sort of a motion without at the same time bringing about a disjunction between the two bodies. Thus pressure is a contact which persists. On the other hand, the impact brings about a disjunction of the two bodies after the event of conjunction and hence does not persist. It is evident that conjunction and disjunction are thought of in terms of relating principles.[a]

In conclusion, it should be emphasized that the attributes, as conceived by the *Nyāya-Vaiśeṣika*, are not arbitrary. The twenty-four attributes already mentioned are so chosen that they could explain the knowable properties of the phenomenal world as well as of the knower himself. This is in keeping with the integrated view of the *Nyāya-Vaiśeṣika* concerning the world of reality.

MOTION

In the Indian view of the physical world, the idea of motion is of fundamental importance. For, it is believed that motion is necessary not only for the creation of the world but for its destruction even. In other words, both conjunction and disjunction, of cosmic or atomic order, are inherent in a substance which serves as the substratum of motion. The characteristics of motion, according to the *Nyāya-Vaiśeṣika*, are: (i) one kind of motion is possible at a time in one substance; (ii) the substance experiences motion from without; (iii) motion exists only for a few moments; (iv) it is produced by infinite substances with limited forms; (v) it has no quality and (vi) it is destroyed by the effect it produces in a particular direction. The *Vaiśeṣika sūtra* says that motion is non-eternal and has the character of being an effect and a cause. In particular, it is the cause of velocity and elasticity.

It has been mentioned earlier that one of the six categories of the *Nyāya-Vaiśeṣika* system is action (*karman*). Action is thought of in terms of throwing upwards (*utkṣepaṇa*), throwing downwards (*apakṣepaṇa*), contraction (*ākuñcana*), expansion (*prasāraṇa*), and going (*gamana*).[b] In fact, the five actions represent the *Nyāya-Vaiśeṣika* concept of motion. Evidently, in these

[a] *PBh.*, pp. 649 ff.

[b] *VS.*, **1**, 1.6.

five actions what distinguishes the one from the other is the direction in which the action takes place. Throwing upwards and throwing downwards are obviously vertical motions in opposite direction brought about by effort. Both contraction and expansion are explained in terms of conjunction and disjunction of particles in space. *Gamana* is motion in general in any direction. It is conceived of in terms of conjunction or disjunction with points of space in diverse directions. It is quite clear that in this scheme, motion has not been conceived with reference to both space and time.

The *Vaiśeṣika* holds the view that matter in its atomic or gross state is intrinsically static. The inert matter is set in motion by some quality present in it. For example, the falling motion is due to the quality of gravity present in it. The quality of fluidity is the cause of flowing. Even throwing upwards or downwards is caused by the quality, effort. *Gamana* takes place as a result of the two qualities, viz. conjunction and disjunction. In the case of atomic matter the position appears to be different. It is pointed out that only the free atoms which exist at the time of total destruction of the universe are in motion. The first cause of this motion is held to be *adṛṣṭa* (the unseen). In the *Nyāya-Vaiśeṣika* concept of motion, *adṛṣṭa* seems to occupy an important position. Even some of the natural movements like attraction of needle by magnet, flow of air, upward rise of sap in the plants, etc., are considered to be due to *adṛṣṭa*.[a]

The motion of free atoms caused by *adṛṣṭa* is responsible for the coming into being of the material world. The free atoms have two types of motions—creative and non-creative. The former causes conjunction of atoms eventually giving rise to gross bodies. The latter, on the other hand, brings about occasional grouping of atoms.

The *Vaiśeṣika* holds that when a body moves its motion belongs to itself and to no other. One event of motion cannot produce another motion; i.e. it cannot initiate its own kind of motion. This means that perpetual motion is impossible. A body can have at a particular moment one unit of motion which just produces the minimum possible change in the positions of the body. How then could the body have continued motion? In this respect the concept of *saṃskāra*, one of the attributes, is of great significance. There are three forms of *saṃskāra*, namely *vega* (impetus), *bhāvanā* (mental impression) and *sthitisthāpaka* (elasticity).[b] The last has been dealt with already. The second is non-physical in character and hence does not merit attention at this stage. The *Vaiśeṣika* concept of *vega* is important in this respect that it signifies the idea of momentum, for *vega* is stated to be not only caused by motion but also is recognized as a cause of motion. According to Vyomaśivācārya and Śrīdhara, *vega* is caused by *nodana* (impelling push), *abhighāta* (impact) and *saṃyuktasaṃyoga* (forces which set in compound conjunction)[c]. It is, therefore, reasonable to suppose that *vega* is produced by a force or

[a] *VS.*, 5, 1.15; 5, 2.14. [b] *PBh.*, p. 646. [c] *NK.*, p. 647.

an effort and becomes the cause of continued motion in a particular direction until it is smothered by external situations or forces.

In general, the position of the *Vaiśeṣika* is that when a body experiences the first unit of motion caused by impelling push, impact and the like, *saṃskāra* or impetus is possessed by it. On account of this impetus, the body continues to move in the same direction. It is pointed out that the impetus is capable of producing the effect to the same extent and in the same direction as the cause by which it is itself produced and that the body is in motion as long as it possesses the impetus, and the direction is not altered. Thus the impetus maintains the direction of the motion. However, when the moving body comes into contact with an obstacle which would neutralize the quality of impetus, it comes to rest. If, instead, the obstacle cannot neutralize the quality of impetus in full, the motion continues of course with diminished strength.

A causally connected descriptive account of motion of a javelin thrown by hand, an arrow shot from a bow, and of pestle and mortar is found in the *Praśastapādabhāṣya* and the *Nyāya-kandalī* of Śrīdhara.[a] In the case of the motion of a javelin, the desire of the person engaged in the operation with consequent volitional effort results in conjunction of the hand with the javelin and an impelling push. The latter imparts motion to the javelin as well as an impetus. When the javelin leaves the hand, i.e. when the disjunction takes place, the impelling push becomes ineffective while the impetus causes the motion of the javelin, the direction and the distance traversed by the javelin being dependent upon the extent or quantum of the volitional effort applied, resulting in an impetus.

In the case of discharge of an arrow from a bow-string, the desire and the effort operate resulting in a motion in the form of drawing of the string by hand as well as in the arrow and the string. Again, the desire and the effort to discharge the arrow produce disjunction between the string of the bow and the finger. At this stage, *saṃskāra* of the type of elasticity present in the bow tries to restore the original form of the bow. Aided by this elasticity, a motion is produced in the string as well as in the arrow which is now impelled by the string. The impelling push produces *vega* in the arrow, the moment the arrow leaves the string. The arrow then continues to move because of the *vega* and, when the latter is exhausted, becomes subject to the action of gravity and falls to the ground.

In respect of the movement of a pestle,[b] the cause is explained also in terms of desire and volitional effort, conjunction and disjunction. The volitional effort results in an upward motion in the hand first and in the pestle later. Now the desire for downward motion occurs and the corresponding volitional effort produces the downward motion. It is pointed out that the upward motion caused by the impact of the pestle with the mortar is involuntary. In other words, the downward action sets in a reaction and it is the latter that brings about the upward motion in the

[a] *NK.*, pp. 700–706.

[b] Mishra (U.) (1), pp. 210–11.

opposite direction. The point worthy of note is that the impact of the pestle with the mortar as well as the continuance of the upward motion for some time is explained in terms of *vega*.

The *Vaiśeṣika* explanation of the motion of objects is obviously qualitative, considering as it does the motion in terms of change with reference to space only. Nowhere does it appear to take cognizance of another mode of perception with respect to motion, i.e. time. The general idea is that motions are caused by qualities in the substance. This is in keeping with the position that actions and qualities cannot be considered without their substratum, viz. substance.

The falling motion of a body has been examined in considerable detail by the *Vaiśeṣika*. In the case of a body falling vertically due to gravity it is believed that gravity causes the initial falling, and impetus, too, is said to be produced concomitantly. Even though the downward motion becomes subject to the combined action of gravity and impetus, the explanation offered by the *Vaiśeṣika* does not appear to have the connotation of acceleration at all. It would appear that gravity which causes the first unit of motion from which arises the impetus, becomes ineffective, and the subsequent falling motion is considered to be due to impetus alone. Gravity as understood by the *Vaiśeṣika* should not be confused with the modern concept of gravity. It may be reiterated that in the *Vaiśeṣika* school gravity is a quality having a causal function with falling as its effect.

Historically, the impetus theory appeared in Europe, only in the fourteenth century A.D. though John Philoponus of Alexandria had put forward a similar view as early as the sixth century A.D. In India, however, the impetus theory is unmistakably recognizable in the *Praśastapādabhāṣya* (*c.* fifth century A.D.) and the elements of the theory can be found in the *Vaiśeṣika sūtra* which, as indicated already, is pre-Buddhistic (*c.* seventh century B.C.).

ĀKĀŚA, SPACE AND TIME

Among the Indian physical concepts those relating to *ākāśa*, space and time deserve special mention.[a] As has been seen, earth, water, fire and air are material substances; as produced substances they are non-eternal. However, in the form of atoms they are eternal. On the other hand, *ākāśa*, space and time are non-material, eternal and all-pervading even though they are grouped along with the first four under the category of substance.

Among the three, it is *ākāśa* alone which has a special quality like the first four, and its specific quality is sound. This specific quality, however, exists only in some part of the ubiquitous or all-pervading *ākāśa* at a particular instant, while the specific qualities of the other four substances respectively pervade in them. Another aspect of *ākāśa* is that

[a] Bhaduri, pp. 164–228.

though non-material, it is recognized as one of the five elements, and thus is capable of playing its role in the formation of gross bodies. All corporeal substances are held to be in direct contact with *ākāśa* which is a vast expanse or an infinite continuum. The auditory organ is also regarded as of *ākāśa* itself as a logical necessity. For, if the auditory organ is to experience the quality of sound of which *ākāśa* is the substratum, the organ itself must be in the very nature of *ākāśa*.

Space and time differ from *ākāśa* in this respect that there is no specific quality for each of the former. Both space and time have, however, the other five qualities as *ākāśa*, viz. number, dimension, distinctness, conjunction and disjunction. As indicated already, these five qualities which are regarded as generic, are shared by all the nine substances.

The *Nyāya-Vaiśeṣika* holds that space is the cause or basis of the ten notions of east, west, north, south and the like with respect to one material object relative to another material object as the starting point of the limit. For the sake of usage the ten literal names like east, west, etc., are coined with reference to the contact with the reference-body, viz. sun. Even so, space is regarded as one, eternal and all-pervading. Space appears to have been conceived by the *Nyāya-Vaiśeṣika* as a positionally relating one, providing an arrangement or order to discrete objects so that their positions become intelligible. Because of space the corporeal substances are cognized as occupying different places. Distance is not understood as parts of stretch of space, but thought of as number of conjunctions with reference to the observer. If the number of conjunction is more between the observer and a particular object than it is with another object, the fomer is observed as being prior to the latter. The transitive principle which relates the two objects and which points out their posteriority or priority, is space. Thus space is not a mere receptacle into which bodies are filled here and there. It is an objective reality possessing certain qualities. However, the qualities like remoteness, proximity imply an observer as a frame of reference. The presence of an observer is necessary, but not sufficient condition; for, according to the *Nyāya-Vaiśeṣika*, the object has to be in conjunction with space which is a real substance.

Like space, time is another real which is the cause or basis of production, persistence and destruction of all produced things. It is also the basis for common notions such as *kṣaṇa*, *lava*, *kāṣṭhā*, *māsa*, *ṛtu*, *yuga*, *kalpa*, *pralaya* and *mahāpralaya*. Priority (*aparatva*) or posteriority (*paratva*) as a quality of the produced things resides in it with reference to the number of solar revolutions (*ādityaparivartanāni*). One complete revolution of the sun round the earth (equivalent to a day) is one solar revolution which is the basis or standard of reference. If A is regarded as prior to B and if A and B are existing, it means that the former must have been connected with a greater number of solar revolutions than the latter. Time is the relation or the linking factor between the unit and the universal solar revolution. It is therefore objectively real. Besides, time is essential as

the efficient cause of notions such as 'youth', 'old', etc. In other words, because of time, the growth and decay in material objects are perceived.

Time is thought of in diverse ways on account of the diversity of such situations as production, continuance and disappearance of all things. Events derive their chronological order on account of time. The past, present and future are empirical divisions of time. The coming into being of an effect indicates the future; its persistence means the present; and its destruction connotes the past. The notions of past and future are with reference only to the present, according to the *Nyāya-Vaiśeṣika*. In this interpretation, time is reckoned in terms of its *kriyā* or action also.[a] The present relates, say in the case of falling object, the action of falling and the object; the past means that the connection between the object and the falling action is over; and future refers to such a connection yet to materialize.

Space and time have many things in common in the *Nyāya-Vaiśeṣika*. Yet they are distinctly separate substances, even though they possess the same qualities. The difference lies in interpreting time on the basis of action while space is not conceived of that way.

The Jainas, in general, believe that time is *ajīva* (non-conscious) and without any *kāya*, but eternal and without motion, even though some thinkers among them differ from this viewpoint. The present, past and future are referred to by the Jainas as phenomenal time, *vyavahāra kāla* or *samaya*, i.e. they are intimately connected with certain events or phenomena bringing about changes. Obviously this is 'relative-time'.[b] The Jainas also think that there is yet another time known as *niścayakāla*, i.e. noumenal time. The noumenal time is the basis or support (*ādhāra*) of the phenomenal time. Besides, it is the cause of changes in substances and without it no change is possible. In sum, the Jaina view of time is not wholly different from that of the *Nyāya-Vaiśeṣika*. However, there seems to be one important difference, viz. the Jainas (the *Digambaras*) do not consider time as one and all-pervasive. Instead they hold that there are distinctive time units corresponding to distinctive human experiences. They are the ultimate time-units, called *kālāṇus*, i.e. atoms of time—as indivisible as atoms, discrete and infinitesimal. Each *kālāṇu* is supposed to occupy only one *pradeśa* and hence *kāla* has no '*kāya*'.[c]

While the *Nyāya-Vaiśeṣika* and the Jaina schools recognize the absolute reality of time, the Buddhists and the followers of *Sāṃkhya* and the Vedāntins deny the objective existence of time. The followers of the *Yoga* school of Patañjali seem to accept only *kṣaṇa* (i.e. moment) as the ultimate unit of time and imagine an uninterrupted flow of these ultimate units. The Vedāntins regard time as of nescience (*avidyā*), i.e. time has no reality.

In addition to the foregoing, there are a number of other views about time. For example, the celebrated *Purāṇas* speak of time as all-powerful Deity. The *Yoga Vāśiṣṭha* says that time and space are relative

[a] Mishra (U.) (1), pp. 180–82. [b] *Dr. Saṃ.*, **21**, 22. [c] Mishra (U.) (2), I, p. 321.

thought-models which are dependent upon mind. A few tantrik texts consider time even as *Śakti* which governs creation, persistence and destruction. But these views deserve only passing mention.

HEAT AND LIGHT

HEAT

Conceptually, heat and light are sought to be understood in relation to one of the five elements, viz. fire (*tejas*). As has been seen, according to the *Nyāya-Vaiśeṣika* school, the element fire is material; eternal in the form of atoms and non-eternal in the form of products. The atomic view of the element fire, is generally maintained in the case of heat while the atomic as well as the wave nature of fire, in the case of light.

What happens when a body is heated? The *Vaiśeṣika* and the *Nyāya* schools have considered this problem in considerable detail. It is well known that when a fresh earthy pot is subjected to the action of heat its colour changes, generally into red, and the body of the pot hardens. The *Vaiśeṣika* believes that these changes or fresh attributes take place at the atomic or the particulate level. The *Naiāyikas*, on the other hand, hold the view that they occur in the body as a whole. The former is known as *pīlupākavāda* (argumentation concerning the heating of *pīlus* or particles) and the latter, *piṭharapākavāda* (argumentation concerning the heating of the body as a whole).[a] In either case, during heating what happens is that the fire element plays the active role. The element is considered to be in high motion, producing forcible contact (*abhighāta*) with the object heated. According to Udayanācārya, the fire element is so light and moves with such high speed that it is capable of causing a rupture of the original structure of the body when subjected to heat.

Pīlupākavāda

The *pīlupākavāda* envisages the action of heat at various stages. When an earthy body (pot) is heated, the fire element enters into it with great force, thus setting into motion the earth-atoms. Udayanācārya says that the impact is so strong that the motion produced by the fire element results in the destruction of the previous structure (*vyūha*). As a result, disjunction of atoms takes place, i.e. the dyads are split and atoms become isolated. At this stage, fire destroys the original colour of the earth-atoms which, as a result, attain a native state. Fire now produces in them the red colour. Afterwards, the unseen force (*adṛṣṭa*) causes conjunction of atoms into dyads which ultimately form, through triads, the pot once again. This is evidenced by the fact that before the action of heat the constituent parts of the pot are not hard, while they do become hard after heating.

[a] Mishra (U.) (1), pp. 92–95.

Though a series of events takes place, the *Vaiśeṣika* holds that the original shape of the pot remains the same.

Another interesting aspect of the *pīlupākavāda* is that the whole process is enumerated in terms of distinct stages, and the time necessary for attaining each stage is reckoned in terms of moments—nine, ten or eleven.[a] The heating process involving ten moments, broadly, is as follows: (i) motion produced in the atoms, and isolation of atoms; (ii) destruction of the original colour; (iii) production of the red colour; (iv) destruction of the motion of the atoms produced earlier; (v) production of the creative motion between the atoms; (vi) disjunction between the atoms and *ākāśa*; (vii) destruction of the conjunction produced earlier; (viii) coming into being of productive conjunction; (ix) production of the dyad; and (x) production of the red colour in it, and formation of the triad. Likewise, details are also given of processes involving nine or eleven movements. There are even processes involving six, five, four or three moments, in consonance with the different stages of the processes reckoned. What is of importance in this scheme is that the colour of the pot is produced by the colour of the triads which owe their colour to the constituent dyads which, in turn, owe it to the colour of the atoms themselves.

Piṭharapākavāda

According to the *piṭharapākavāda* which sets forth the view that the colour change takes place in the entire body of the pot, i.e. the pot in the oven or the furnace remains structurally intact. It does not undergo any change in size or shape, and the invisible process of disintegration at the level of atoms is wholly untenable.

These two views obviously try to explain a common phenomenon on logical grounds without going into the quality or quantity of heat itself. The idea relating to the differences in the sources of heat is also not thought of. Different types of fuels are stated to be different forms of fire. There is a view held by Vijñāna Bhikṣu that heat is latent in the fuel and under favourable conditions it breaks forth. Udayanācārya has given expression to a more rational view that the solar heat is the source of all forms of heat manifested.[b]

Another aspect of the element fire *vis-à-vis* what is known as *pāka* deserves consideration. *Pāka*, in general, seems to connote conjunction of the element fire in different ways with earthy substances. For example, when a mango fruit is kept surrounded with straw, the heat produced changes its colour from green to yellow without affecting the taste of the fruit. This is a case of conjunction involving fire element. Similar types of conjunctions are possible resulting in the change of taste, smell and touch. The *Nyāya-Vaiśeṣika* tries to explain different transformations such as production of milk from grass, formation of curd, cream, etc., on the basis of conjunction involving fire atoms.

[a] Mishra (U.) (1), pp. 84–89.

[b] Das Gupta, I, pp. 327–29.

LIGHT

In respect of light, the concept found in the *Nyāyasūtra* of Gautama and elaborated upon by Vātsyāyana in the *Nyāyabhāṣya* deserves special mention.[a] How is the object perceived by the eye or the visual organ? As noted before, the element fire is the principle of the visual (sensory) organ. Its prominent qualities are colour and touch, while its special quality is colour. It is pointed out that the light rays emanate or issue forth from the eye and get into contact with the objects, large or small, in the same way as there occurs the contact between the light ray (going out from the lamp) and the object. The rays which issue forth from the eye, if obstructed by an intervening object, cannot have the direct contact with the object. Hence the latter cannot be perceived in such a situation.

Then how is the colour perceived? Perception of colour is stated to be the result of the presence of several components and also the character of colour itself. In addition, the character of the colour should become manifest, in order that it be perceived. The light rays coming out from the eye have their colour *unmanifested*. Hence they are not perceived. Light, in general, is stated to possess a diversity of character, viz. (i) both colour and touch manifested (sun's rays perceived by eye and skin); (ii) colour manifested but touch unmanifested (light from the lamp or moon seen by eye only); (iii) touch manifested but colour unmanifested (as in hot water); and (iv) both colour and touch unmanifested (rays from the eye itself).

The view regarding the perception of objects larger than the size of the eye is very interesting. According to the *Nyāya-Vaiśeṣika*, just as *tejas* of the burning wick of a lamp gradually spreads out in ever increasing circles and illumines the objects of various sizes, so also the *tejas* in the eye goes out and spreads in wider circles apprehending the objects of different sizes. It is held by the *Mīmāṃsakas*[b] that, like a ray of light, the stretch of vision also goes on expanding gradually, the range of vision depending upon the extent of the stretch. The extent of this stretch itself is said to terminate at the object, perhaps encompassing it. It is even stated that the vision of the rays emanating from the eye would not proceed beyond the object in view.

The *Mīmāṃsakas* also think that the flame is the collection of a large quantity of light particles at the burning zone, say wick, and that the light particles are in a state of high motion. Further, they even recognize a sort of radiation diffused by the flame, proceeding away from the burning wick.

As regards reflection, a curious view is expressed by the followers of the *Nyāya* school. The mirror is believed to be possessed of a particular colour as an intrinsic part of its very nature. When a man stands before it, the light rays emanating from the eyes strike the mirror and are

[a] *NBh.*, 3, 1.38–70.

[b] *Śl. V.*, 4, 47–48.

turned back. Again they establish contact with his own face. The reflected image is perceived as a result of the peculiar colour of the mirror's own surface.[a]

It will be seen from the foregoing observations that the speculation concerning light centres round the fact that the rays issue forth from the eye itself to establish contact with the object. The contact-theory, as it may be called, seems to derive its sanction from (i) the fact that the principle of visual organ is *tejas* (fire) and (ii) an observation that the light rays appear to emanate from the eyes of 'night-walkers', i.e. cats and other feline animals. The *Nyāyabhāṣya* asserts that there is no justification for the assumption that there is a difference of character between the eye of the cat and the human eye.[b]

Of particular interest are the different views about the characteristics of the visual sense organ itself. The *Nyāya-Vaiśeṣika* holds that the eyes are produced mainly from the ultimate particles of *tejas* so that they apprehend colour alone. It is pointed out that this particular type of production is rendered possible by *adṛṣṭa*. The Buddhists, however, believe that the blue eyeballs represent the visual organ. These eyeballs, which are material, perceive the external objects because of external light and the past deeds of the observer. They do not subscribe to the idea that the visual organ moves up to the object of perception at a distance. In respect of the number of visual organs, too, there are differing views. The author of the *Nyāyabhāṣya*, Vātsyāyana, states that there are two independent eyes and hence two sense organs of sight. Udyotakara, in his *Nyāyavārtika*, asserts that there is only one organ of sight. This view is supported by the later exponents of the *Nyāya-Vaiśeṣika* like Vācaspati Miśra and Viśvanātha as well as by the Buddhist, Vasubandhu.

SOUND

There are different views about the production and propagation of sound. The followers of the *Nyāya-Vaiśeṣika* school consider sound as a quality. The substance in which sound subsists as a special quality corresponding to the auditory sense organ, is *ākāśa*. In the *Nyāya-Vaiśeṣika* view sound is a produced phenomenon having a beginning as well as an end. Even so, it is not believed to be coeval with the substance in which or by which it is produced, because experience reveals that sound moves out of the substance.

Two types of sound are recognized: (i) articulate and (ii) noise in general. The first is considered as the one that proceeds from mind and self. An effort on the part of the subject brings about the conjunction of the self with air. This conjunction produces in air a certain movement. The air then strikes the region of throat to produce letter-sound, i.e. the articulate one, in contact with *ākāśa*.

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[a] *NBh.*, 3, 1.50.

[b] *NBh.*, 3, 1.44.

The noted exponent of the *Vaiśeṣika* school, Praśastapāda,[a] is of the view that sound is produced always in series which may be likened to the series of water ripples. It has been stated that these wave motions, ripple-like as they are, occupy successive points in *ākāśa*. The first sound causes the second one. As soon as the latter is formed, the former (as the cause) gets destroyed. This kind of production and destruction goes on in a chain, and what is perceived by the ear is the last of the series. In other words, the first sound so produced and, for that matter, the intervening ripples of sound, are not heard. Yet in this way the auditory organ is said to be connected with the source of sound through the successive movements. The latter are indeed a result of the cause and effect relationship. The first movement is the cause with the second as the effect, the second is the cause with the third as the effect and so forth.

When a drum is struck by a stick the impact is believed to set up vibrations as a consequence of which sound is produced in all directions. The mechanical impact is held by the *Nyāya-Vaiśeṣika* to be the efficient cause while *ākāśa* alone is the true substratum of sound. Further, while *ākāśa* is an eternal substance, sound is a transient quality because it is related to the notion of being produced and destroyed.

The position of the followers of the *Mīmāṃsaka*[b] school is entirely different in this respect. They believe that sound is eternal and not a produced phenomenon. The movement of the air and the perception of sound appear to have been linked together by the *Mimāṃsakas*. Owing to an effort, say when one speaks, the internal air is said to acquire a certain forceful movement and reach the *ākāśa* of the ear, thus imparting to the auditory organ a faculty or potency. It is only when this faculty, imperceptible as it is, occurs that sound is heard. The changes perceived with reference to the intensities of sound are believed to be due to the fluctuations in the air-current itself. In this way the *Mīmāṃsakas* explain the propagation of sound while strictly maintaining the eternality of sound. This is in line with their philosophical position, viz. that *śabda* or word (Veda included) is real and eternal.

The Jainas believe that sound is neither a substance nor an attribute of *ākāśa*, but is a sort of a modification of matter.[c] When the *skandhas* or aggregates of atoms come in contact with one another sound is said to become manifest and travel as such to the ear. The *Sāṃkhya* view is that the auditory organ as a part of the all-pervading *ākāśa* expands imperceptibly into the region where sound is produced. And *ākāśa* itself is formed out of the *tanmātras* (subtle states) of sound.

It will be observed from what has been stated above that the *Nyāya-Vaiśeṣika* school alone tries to explain the phenomenon of sound in a causal sequence. The other schools attempt to accommodate the phenomenon into their philosophical views.

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[a] *NK.*, pp. 692–94.

[b] *Śl. V.*, 6–23, 88–127.

[c] Mishra (U.) (2), I, p. 319.

In the end, emphasis may be laid on some important aspects of the particular Indian physical concepts in relation to the history of science. The earliest reference to the concept of natural law (*ṛtam*) can be found in the *Ṛgveda*. Likewise the doctrine of elements is probably earlier than that of the Greek thinkers. This doctrine in some form or the other exerted considerable influence on different Indian systems of thought including the *Cārvākas*. Atomism, which was a significant mode of thinking among the followers of the *Vaiśeṣika*, *Nyāya*, Jaina and the Bauddha schools, as mentioned already, developed on logical lines.

The *Vaiśeṣika* system has played an important role in the growth of physical ideas in India. It had assumed a definite shape by the sixth century B.C. In the history of science, sixth century B.C. has been regarded as the period which heralded the dawn of what has now come to be known as the Greek Science. The *Vaiśeṣika* system contains in it the most important ideas on matter and motion, enunciated later by some of the leading Greek thinkers including Aristotle (from the beginning of the sixth century to the close of the fourth century B.C.). Among the Greeks there were distinctly separate views and explanations of the knowable world. But there appeared no single system of the type of *Vaiśeṣika* among the Greek thinkers.

It is not a mere historical situation that the *Vaiśeṣika* system presented in an aphoristic style certain physical concepts at an earlier period, and that later there were similar ideas streaming along independently among the Greeks. It is probable there was then a movement of ideas as the Greeks and the Indians came together before and after Alexander's invasion. Even some learned historians of science have unhesitatingly suggested that the origins of some of the Greek ideas can be traced to India also. It is very likely that the *Vaiśeṣika* school, in its systematized form, might have attracted and stimulated the like-minded people elsewhere including the Greek thinkers.[a]

Lastly, the *Nyāya-Vaiśeṣika* concepts present an integrated view of the world-stuff or substance. The four material elements (earth, water, fire and air), the three non-material (*ākāśa*, space and time), the conscious self and the internal organ, mind, constitute the *substance*. This integrated conceptual presentation is of particular significance from the point of view of modern scientific epistemology. For, the latter is still unable to clarify the conceptual inadequacies concerning substance.

[a] Subbarayappa (2), pp. 21–34.

10 WESTERN SCIENCE IN INDIA UP TO THE END OF THE NINETEENTH CENTURY A.D.

B. V. SUBBARAYAPPA

THE growth and ramification of several scientific thoughts and technological practices dealt with in the preceding chapters reveal, on closer analysis, that the Indian culture-area occupied a distinct place in the history of science during the ancient and medieval periods. A comparative study of the Indian scientific thought with that of Europe shows that, while Europe was passing through the Dark Age from about the fifth to eleventh centuries A.D., India had her period of glory in the Classical Age and made remarkable progress in such fields as mathematics, astronomy, iatro-chemistry and metallurgy, even right up to the twelfth century A.D. Thereafter the creative endeavour showed signs of decay due largely to the traditional compulsions and political vicissitudes.

Traditionally, the free involvement of different productive classes did not materialize as a result of caste distinctions on the one hand and a sort of mutual aloofness among various branches of production on the other. The professionalists—the artisans and craftsmen—engaged themselves in their respective productive operations practically without any communication with one another. They could not in addition receive the necessary educational training. Thus training of the mind did not go side by side with the training of the hands. Moreover, the latter was passed on from one generation to another within the rigid structure of caste-governed professionalism which became eventually detrimental to the augmentation of mobility which alone could foster changes in techniques. More often than naught it was a return to the hereditary practices whenever forces of change raised their heads. Undoubtedly, the Indian artisans possessed the ingenuity to produce outstanding pieces of workmanship in the seventeenth and eighteenth centuries; for the Indian manufactures were of a high order and enjoyed reputation in the adjoining as well as remote countries. Nevertheless, the ingenuity of the artisans depended, for its fuller expression, upon the stimuli received from the social framework of the times. Subservient as they indeed were to the higher and exploiting sections of the society, and hierarchically existing as they did as one of the lowest social

strata, the artisans were in no fortunate position to receive encouragement, from outside or inside, which could nourish and augment their inventive capabilities. Moreover, the craftsmanship, by and large, went by birth, and there was even a certain amount of rigidity among the craftsmen themselves, which was not permissive of cementation with any veneer of excellence outside its tradition.

Politically, a sense of insecurity seemed to have been round the corner of the Indian society in the later medieval period. Naturally this affected the merchant class as well as the artisans. The former could not rear large productive organizations, and necessarily their commercial assets went underground in the form of gold and silver, jewels and other ornaments. Medieval India was indeed rich in these metals. The Frenchman Bernier who travelled in India from 1656 to 1668 says: 'It should not escape notice that gold and silver, after circulating in any other quarter of the globe, come at length to be absorbed in *Hindostan*.'[a] Gold and silver came to India from America, England, Portugal, France, Holland, Turkey, Yemen, Iran, etc., in exchange for the Indian manufactures, while the importation of articles into India did not occasion the export of gold and silver, the returns being again in the form of the Indian merchandise. Even so, the wealth of the country did not result in any industrial investment, leading to productions on a large scale. There were no doubt enterprising business houses in different parts of India. But the political upheavals which came up frequently on the scene acted as a drag on the growth of an industrial middle class. One of the results was that the Indian craftsmen could not be engaged in large numbers under the umbrella of big industrial production. Their work remained as handicrafts, depending upon the whims of their patrons. Such a situation was inherently incapable of bringing prosperity to the craftsmen who were really poor, catering out of necessity to the rather inhuman tendencies of the patrons including merchants. According to Bernier again: 'The protection afforded by the powerful patrons to rich merchants and tradesmen, who give the workmen rather more than the usual wages, tends also to preserve the arts. I say rather more wages; for it should not be inferred from the goodness of the manufacturers, that the workman is held in high esteem, or arrives at a state of independence. Nothing but sheer necessity or blows from a cudgel keeps him employed; he never can become rich, and he feels it not a trifling matter if he has the means of satisfying the cravings of hunger and of covering his body with the coarsest raiment. If money be gained, it does not in any measure go into his pocket, but only serves to increase the wealth of the merchant who, in his turn, is not a little perplexed how to guard against some act of outrage and extortion on the part of his superiors.'[b]

The social milieu, as noted above, was in the least conducive to any technological innovation. As to the scientific ideas, the traditionally fostered learning was confined to a select class of people who preferred to

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[a] Bernier, I, pp. 226–29.

[b] Bernier, I, p. 255.

preserve it with diligence and care only in the nature of elaborate commentaries. Thus ensued an in-breeding in scientific thinking and, in effect, the creative spirit of India was at its lowest ebb from the twelfth to almost the middle of the nineteenth century A.D.

It is true that India had absorbed already some of the Chinese practical arts such as alchemy, paper-making and pyrotechnics. But the Chinese culture-area was in no better position to provide further stimuli which could make inroads into the Indian scientific thinking and practice. The intellectualism of Arabic science with which India had close links shifted to Europe and, by the twelfth century A.D., Spain, the westernmost province of the Islamic world, developed into a meeting ground of Arabian, Jewish and Christian thoughts, with such Indian elements as were assimilated by the Arabian men of science. In the succeeding two centuries it was Europe which provided a social situation, as will be seen below, that was favourable to certain new intellectual endeavours. India could well have looked to Europe and derived inspiration from what was happening in Europe then. But, again, the political and social factors appear to have overpowered the knowledge-seekers and innovators, with the result that India had to wait patiently till the western science was introduced by the Europeans who came as traders first and governed the country later.

RENAISSANCE IN EUROPE

The nomenclature, western science, is intended here to mean that spectacularly fruitful activity commonly referred to as the modern science, which developed its first roots in the intellectual efflorescence of some western countries in Europe notably Italy, France, England and Germany in the sixteenth and seventeenth centuries A.D. It is well recognized that western science owes its origin to the Renaissance (Fr. *renaître*; Lat. *renascari*: to be born again) which some of the European countries experienced in the fourteenth and fifteenth centuries A.D. The reason is not far to seek; for the Renaissance, marked as it was by an outburst of individualism, a spirit of free enquiry and new intellectual vigour, produced a stimulating effect on the methods of investigating or inquiring into the observed phenomena. The traditional and authoritarian views which held the ground for centuries were subjected to searching rational analyses and, as a result, the old theories began to yield place to the new. In consequence, new concepts of matter and motion, an equally new way of reasoned interpretation of the astronomical observations, fresh approach to the study of physiology and the like, devoid of religio-philosophical undertones, emerged. It should be emphasized that the Renaissance itself was an effect of several influences which converged at that time. Although opinions may differ on the exact factors which were causative of the Renaissance, it is interesting to note that 'while it is true that the countryside gains by the habitual presence of its natural leaders, yet, in an age of slow communication, country life gives little opportunity for the contact of

mind with mind which leads to intellectual culture and creation. On the other hand, the city life of the leisured and intelligent classes in northern Italy gave an ideal environment for the birth of the Renaissance'.[a] Further, there was in that period an increase in commerce and an expansion of urban living. The artists and craftsmen became a part of the urban population, having had their share of prosperity and recognition by the widening upper classes who possessed the requisite wealth for material well-being. The new world was under exploration, and the newly acquired treasures gave leisure and comfort for intellectual pursuits. The navigation with the use of astronomical instruments and the abiding interest in cartography brought about not only a widening of the horizon of the physical world but also of human intellect. In particular, astronomy, mathematics, medicine and mechanics assumed new dimensions, meriting serious and imaginative attention.

WESTERN SCIENCE AFTER THE RENAISSANCE

The three centuries, sixteenth to the eighteenth, constitute the most important formative period in the development of modern science. The work of Gilbert (1546–1603) on magnetism, the importance of recording all available facts leading to the formation of general laws by induction as emphasized by Francis Bacon (1561–1626), realization of the importance of new mathematical methods for studying physical phenomena as stressed by René Descartes (1596–1650), the rise of mechanics and astronomy due to the bold approach to them of Galileo (1564–1642) and Newton (1642–1727), the work of Harvey (1578–1657) on the circulation of blood, morphology of the stellar universe, discovery of oxygen, overthrow of the caloric theory of heat, wave-nature of light, and the study of current electricity, were among the most spectacular landmarks of the period. The nineteenth century began with the enunciation by Dalton of the atomic theory which afforded a new interpretation of matter and motion. The nature of electromagnetism and the work of Faraday on electricity had a profound impact upon the knowledge and application of the new form of energy. Towards the middle of the century the law of conservation of energy was established on firm grounds. Furthermore, the biological world acquired a new meaning by permitting a penetrating insight as a result of the theory of evolution propounded by Darwin. Both the physical and biological sciences advanced rapidly in the latter half of the nineteenth century providing new knowledge of alike macrocosm and microcosm. The closing two decades of the century witnessed some remarkable experiments which led to the discovery of X-rays and radio-activity. More significantly, a break-through occurred in respect of the atomic structure, velocity of light and energy distribution in a black-body spectrum. In the early decades of the twentieth century, these gave birth to revolutionary concepts concerning atomic matter, energy, space, time and motion.

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[a] Dampier, p. 101.

It may be emphasized at this stage that the innate strength of modern science lies in its method. For this reason, its character and validity are not governed by any geographical or religio-philosophical positions, which, in the ancient and medieval periods, admittedly impinged upon the science of a nation or culture-area concerned. The scientific method comprises the *induction* which enables formulation of general laws of nature by recognizing uniformity in a set of observations; and *deduction* which helps arrive at inferences of even the unobserved ones from relevant observations. There is yet another aspect of the scientific method which, in general terms, relates to the formulation of hypothesis founded on the analysis of a limited number of observations, and testing its validity by further observations of predicted occurrence, or by means of specially devised experiments of such nature as are based on some theoretical projections.

The foregoing, though briefly sketched, gives an idea of the origin and manifold development of science, based on the scientific method, in the western countries up to the end of the nineteenth century. Alongside, it must be noted that the industrial technology marched ahead, particularly as a result of the Industrial Revolution which occurred in Britain in the middle of the eighteenth century in the wake of the invention of important machinery or mechanical aids, exploitation of mines and effective utilization of steam power. New factories grew up and the new modes of production even changed the complexion of the social structure. Faraday's work on electricity soon led to its application to industries and lighting systems. Chemical industries were established in increasing numbers, and the natural resources exploited for human benefit.

The finished products which developed export potential engendered a new economic movement in different parts of the world. Thus, western science and the associated industrial enterprise could not be contained in the countries of their origin. They began to diffuse, slowly but steadily, to the new lands, both in the East and the West, some of which gradually became their economic and political colonies.

A close examination of such a diffusion of western science from the European countries reveals certain important trends, as indicated in a recent study in terms of a three-phase model.[a] First, the European, for reasons commercial or political, comes into direct contact with the new land and becomes deeply involved in investigations of the latter's flora, fauna, minerals and the like, on which he brings to bear the training in and knowledge of systematic observations which he had witnessed earlier in his own culture-area. Thus, in the beginning, botanical, zoological and geological explorations appeal to him more than any other branch of modern science, and the fresh knowledge gained by him in the process is fed back to the European savants engaged in such investigations. Secondly, there spring up in the new land a number of institutions and scientific establishments which noticeably become instrumental for widening the range of

[a] Basalla, pp. 611–20.

investigations, even so well within the knowledge and training obtaining then in the European countries. In the third phase, the new scientific endeavour acts as a stimulus and attracts the intellectuals among the natives, thus laying the foundation for the promotion of modern science in the new land.

Historically it is interesting to note that in the latter half of the eighteenth century, the biological explorations stimulated interest in the natural history of even far off lands such as India, Australia, Antarctica and the Malayan Archipelago. In addition, the commercially important plants and minerals of the new lands held out great promise for the European trading companies which in their own interest encouraged systematic investigations. The European naturalists, too, were eager to add to their knowledge of botany, zoology and geology by visiting the new countries concerned.

EUROPEAN TRADERS AND MISSIONARIES IN INDIA

The Portuguese

The early European traders to have reached India across the seas round the Cape of Good Hope were the Portuguese; and this happened towards the close of the fifteenth century. In 1510 they occupied Goa (the first Portuguese base on the Indian soil) and soon built up a dominion on the western coast. From the point of view of the history of the implantation of western science on India, mention should be made of Garcia da Orta (1479–1570), the Portuguese physician and botanist who came to Goa in 1534 and spent the rest of his life of 36 years in western India. He grew in Goa a botanical garden in which he nursed a number of medicinal plants. He studied scientifically the flora of the region. His work entitled *Colloquies dos simples e drogos de cousas medicinais da India compostos pelle Doutor Garcia da Orta*, which was printed in India in 1565, contains an account of the local plants and fruits.[a] Apart from Garcia da Orta, we know very little of the other investigators, nor of the attempts made by the Portuguese authorities to bring to India the western scientific knowledge. It may, however, be noted that some new types of plants which included coffee, tobacco, maize and the like were introduced into India during this period. Thus in the sixteenth century India was able to receive and nurture a few western botanical elements.

The Three East India Companies

The beginning of the seventeenth century saw the formation of two East India Companies—one in Britain (1600) and the other in the Netherlands (1602), for trading in the East. The former, under the name 'The Governor and Company of Merchants of London Trading into the East

[a] Burkill, p. 17.

India', was granted a Charter by Queen Elizabeth I on the last day of 1600. This Company traded at first with the Spice Islands, and it was only in 1608 that it could send its first vessel to Surat. The latter, under the name 'The United East India Company of the Netherlands', set foot on the Malabar Coast a little earlier. The French East India Company came into being in 1664. The European naturalists, medical men, engineers and other technical men who came out to India in association with such commercial and trading enterprises were responsible in no small measure for the introduction of western science in India. Of them, as will be seen later, the British, after establishing their supremacy in 1757, played a great role in not only establishing a number of scientific and technical institutions but also promoting scientific investigations in India.

Jesuit Missionaries

The seventeenth and eighteenth centuries also witnessed the entry into India of a number of Jesuit missionaries (belonging to a religious order of the Roman Catholic Church, founded in 1534 by Ignatius Loyola) who carried with them the then prevalent learning in Europe in astronomy, geography and natural history. Unofficial agents as they indeed were of the Portuguese Company trading in India, the Jesuit missionaries were also active in the political field particularly in the Mughal court. Fathers Antonio Ceshi (mathematician), Johann Grueber and Albert d'Orville (astronomers), Bouchet, Mandeslo, Noël, Boudier, Figuerado, Gabelsperger, Strobl and Tieffenthaler (geographers) spared no efforts in furtherance of their knowledge in the respective sciences. Some of them were associated with the astronomical observatories of Sawai Jai Singh early in the eighteenth century. To what extent their knowledge of western science was able to influence the local *paṇḍits* and rulers cannot be said with certainty. Likewise, in what form the Indian scientific ideas which they carried with them to Europe were assimilated into the then evolving scientific knowledge is a moot point. However, in the field of geography of India the latitude and longitude measurements which were determined scientifically by some of the Jesuit missionaries contributed not a little to the geographical knowledge of India.

SCIENTIFIC INVESTIGATIONS AND INSTITUTIONS DURING THE SEVENTEENTH AND EIGHTEENTH CENTURIES

The first glimpses of modern scientific investigations that India had were those concerning its natural treasures and features. The flora and the fauna, minerals, geographic characters, climatic conditions and the like attracted the attention of the versatile Europeans who were either in the employ of the trading companies or independent missionaries and explorers. Some of them were trained scientists while the others went about with almost an insatiable thirst for the natural knowledge of the country.

In the eighteenth century, the commercial policies of the Britishers gave considerable encouragement to the study of the economically important plants, minerals and other natural products of India. Moreover, the country's climatic as well as geographical knowledge, essential for military purposes, was an important factor. Thus the British East India Company prudently promoted botanical, meteorological and geological investigations, as well as a survey of India on scientific lines. To begin with, the investigators were obviously Europeans; and Indians could get into them only after the country had a system of scientific and technical education which trained them. The following is a brief account of some of the important scientific efforts made in India in the seventeenth and eighteenth centuries.

BOTANICAL STUDIES

In Europe, the botanical investigations in the early seventeenth century were mainly confined to the collection and identification of plants, their classification and study of morphology. The European naturalists who came to India during this period were, by and large, either physicians, administrative officers or missionaries, who acquitted themselves as efficient collectors and classifiers of the Indian flora.[a]

When the Dutch took possession of the Malabar Coast from the Portuguese, the Dutch naturalists evinced keen interest in the flora around them. The Governor of Dutch Possessions, Heinrich Van Rheede tot Drakenstein (1637–1692), studied a number of plants and seeds with the help of the European surgeons with whom he came in contact and also the Malabar medical practitioners whom he employed for the purpose. He was perhaps among the first to get the illustrations of a number of plants drawn. His work, *Hortus Malabaricus*, was published in 12 volumes (Amsterdam, 1686–1703) with 794 plates.[b] It is significant that on this work Karl Linnaeus, the renowned Swedish botanist, based the nomenclature of the Indian plants in his *Species plantarum*.

On the Madras Coast at this time the two Britishers, James Petiver, who was an apothecary, and Charles Du Bois, who was an employee of the East India Company, were engaged in the collection of plants. Petiver used to send the material to the Westminster physician, Leonard Plukenet, who spared no efforts to publish the copperplate illustrations of them under the name *Phytographia*.[c] On the Madras Coast was also working a Dane, Johan Gerhard Koenig (1728–1781), who had worked earlier with Karl Linnaeus. Koenig joined the Tranquebar Mission as a surgeon in 1768, and later became the Natural Historian of the East India Company in the

[a] It would appear that up to the end of the nineteenth century there were as many as 457 persons interested in the botanical explorations, among whom 104 were surgeons or physicians and 111 were administrative officers. —Burkill, p. 232.

[b] King (G.), p. 904.

[c] Burkill, p. 9; King (G.), p. 905.

Madras Presidency. It would appear that he formed a small group interested in botanical studies under the name 'The United Brothers'[a] who used to collect plants, exchange specimens and send them to Europe for ensuring proper nomenclature and description. According to King:[b] 'Three of these brothers, Heyne, Klein and Sottler, were missionaries located near Tranquebar. Gradually the circle widened and, before the century closed, the enthusiasm for botanical research had spread to the younger Presidency of Bengal, and the number of workers increased to about 12, among whom may be mentioned Fleming, Hunter, Anderson, Berry, Roxburgh, Buchanan and William Jones'. On his part, Koenig made huge collections of plants and used to send specimens to the University of Lund in Sweden. In addition, he introduced Linnaeus' binomial system of nomenclature in India.

ROYAL BOTANIC GARDEN

In the history of the botanical and horticultural investigations in India, a special significance attaches to the role of a garden known as the Royal Botanic Garden[c] (now Indian Botanic Garden). As the former President of the Royal Society of London, Joseph Banks said:[d] 'The Botanic Garden was established with fourfold purposes of conferring economic benefit to the region, increasing their resources in food and raw materials, importing from other parts of the world newer types of plants of economic importance and acclimatizing them here, as well as for extending the interesting science of natural history and particularly botany.' The garden came into existence as early as 1787 at Sibpur on the west bank of the river Hooghly under peculiar circumstances. At Calcutta, the Burma teak was being used to build freight vessels and this posed a challenge whether teak could be grown near Calcutta or not. Robert Kyd, who was then Secretary to the Military Department of Inspection, suggested that an attempt be made to grow teak in a botanic garden, and chose an extensive area for the garden, just opposite to where he lived. A trial was then made to grow teak in about 40 acres. Now enjoying an extensive area of about 300 acres,[e] the Botanic Garden (earlier popularly known as the 'Company Bagh' denoting that it belonged to the East India Company) represents the devoted and systematic efforts of a number of botanists. Robert Kyd, who had raised a small garden himself and who was noted for his horticultural interest, became the first Honorary Superintendent of the Garden, and introduced some 300 species in the Garden which evidently was the first of its type at that time.

Well aware of the importance of the economically useful indigenous plants, Kyd recommended to the government to establish a nursery stock of plants and later disseminate such of them as were extremely beneficial to

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[a] Maheshwari and Kapil, p. 5.
[b] King (G.), p. 905.
[c] Biswas, pp. 26–23.
[d] Santapau, p. 2.
[e] King (G.), p. 906.

those who would cultivate them. In such an attempt he saw an extension of Indian commerce, and increase in national income. The East India Company, too, was not unaware of the benefits of this scheme. While whole-heartedly approving the proposal, the Company laid special emphasis on the cultivation of the commercially beneficial cinnamon; Kyd tried to grow several kinds of economic plants during his six years of office.

After the death of Robert Kyd in 1793, William Roxburgh, who was then the East India Company's naturalist in the Presidency of Madras, was appointed as the Superintendent of the Garden. Roxburgh who had already established himself as a naturalist of indefatigable energy was noted for his discovery of the indigenous pepper plant at Samulcotta (Godavari district of Andhra Pradesh). To him the Garden owed a great deal for its flourishing form in the first decade of the nineteenth century, as will be seen later.

SURVEY

The political ambitions of the East India Company was, perhaps, largely responsible for organizing extensive survey work with a view to gaining a thorough geographical knowledge of the subcontinent. Nevertheless, as already noted, the Jesuit missionaries and the European travellers who wandered in India possessed some geographical details. Some maps revealing the geography of India, which were published in Venice, Holland, France and England, were based on the traditional ideas and the accounts of some mariners and travellers. In 1723, the French geographer Delisle published a fairly accurate map of the southern coasts of India. Earlier in 1719, Father Bouchet, a French Jesuit missionary, prepared a rough inland map of southern India and from this the well-known geographer Bourgignon d'Anville (1697–1782) published in 1737 his first map of south India, and in 1752 a comprehensive map, *Carte de l'Inde*, at the request of the French East India Company.[a] However, it was the Britishers who initiated in Bengal a scientific survey for ascertaining the geographical knowledge as accurately as possible. And they could do so after their victory at the Battle of Plassey in 1757.

In 1761 Plaisted began the survey work on the coasts of Chittagong. About the same time Hugh Cammeran surveyed the 'New Lands' of the 24-Parganas. His successor, James Rennell, conducted the survey of the Ganges river (1764) with a view to finding a waterway for up-country traffic from Calcutta. In recognition of his untiring work Rennell was appointed by Clive and his Council as the Surveyor-General (1767). By 1777 Rennell and his co-workers had surveyed the Company's possessions in Bengal and Bihar including the Assam frontier. The first *Map of Hindoostan* was prepared by Rennell in 1783. T. D. Pearse of the Bengal Artillery and R. H. Colebrooke recorded a series of observations of latitude and longitude (1774–1795). The other Presidencies—Madras and Bombay—

[a] Phillimore, I, p. 2.

were not lagging behind in their efforts towards surveying the strategically important geographical parts. In the Presidency of Madras, Robert Kelly (1738–1790) and Michael Topping (1747–1796) were the pioneers. Kelly attempted to cover the south peninsula with an atlas of degree sheets compiled from measured routes. Topping, who founded the Madras Observatory (1792) and the Surveying School (1794), advocated 'a continuous series of triangles that should be spread throughout India',[a] and endeavoured to prepare a 300-mile line of triangles along the coast from Madras to Palk Straight. Even though he did not have the necessary knowledge of geodesy, Topping appeared to have favoured a trigonometrical survey of India. Collin Mackenzie of the Madras Engineers, who placed the topographical survey (i.e. delineation of the natural and other features of an area) on a solid foundation, was well known for his survey of the Deccan including Mysore. Towards the close of the eighteenth century substantial progress was made in both the land and coastal surveys. Some parts of Upper India were also surveyed notably by Frederick Sackville (Bundelkhand), Francis White (Delhi), Colebrooke (Rohilkhand) and Webb (Oudh and Gorakhpur). James Blunt surveyed Cuttack and produced a valuable map. Nevertheless, all these could not assume an all-India character even towards the close of the eighteenth century as they were scattered and disjoined.

METEOROLOGICAL RECORDINGS

The usefulness of carefully recorded meteorological observations was noticed long time back by the Europeans—seamen, astronomers, medical officers, engineers and even administrators—who were in different parts of India, not unoften moving from one place to another. As early as 1784, a meteorological diary was maintained at Calcutta by one Henry Trail.[b] Thomas D. Pearse was another who, at Calcutta, recorded the observations of the barometer, thermometer, hygrometer, wind direction and rainfall during the period 1785–1788.[c] Medical officers were also expected to keep meteorological journals at their stations. In 1789 William Hunter recorded observations on the rainfall and climate of Ujjain. However, it was in the nineteenth century that systematic recordings over regular periods at a number of stations became possible, as will be seen later.

THE MADRAS OBSERVATORY

An important institution which came into being in the closing decade of the eighteenth century was the Madras Observatory established in 1792 on the initiative of Charles Oakeley, the Governor of Madras, 'for promoting the knowledge of astronomy, geography and navigation in India'. Earlier, William Petrie, a Member of Madras Government, had set up an observatory, probably the first of its type in the East, at his own expense.

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[a] Phillimore, I, p. 5. [b] Trail, pp. 419–71. [c] Pearse, pp. 441–65.

He transferred his instruments and other equipment to the Madras Observatory. John Goldingham, a Fellow of the Royal Society noted for his astronomical acumen, was the first astronomer who worked at the observatory and recorded a number of astronomical observations, as will be observed later.

THE ASIATIC SOCIETY

In the last quarter of the eighteenth century, the European investigators who were engaged in antiquarian studies, as also in diverse investigations of the natural history of India, felt the need for meeting together with a view to exchanging notes, promoting learned discussions and communicating their own findings. This necessitated the founding of a learned society, and it did not take long to establish one such. Thirty European intellectuals of Calcutta met on 15 January 1784, under the Presidentship of Robert Charles, the second judge of Supreme Court, and resolved to form an association called 'The Asiatick Society'[a] (later known as the Asiatic Society of Bengal and this name was changed in 1936 to 'The Royal Asiatic Society of Bengal') and to hold weekly meetings every Thursday at 7 o'clock. But the mind behind this attempt was that of William Jones, a versatile literary genius and scholar of repute in Latin, Greek, Arabic and Persian. In recognition of his linguistic attainments he was already elected a Fellow of the Royal Society in England before he came to India in 1783 as a puisne judge of the Supreme Court of Judicature at Fort William in Bengal. Jones became the Founder-President of the Asiatic Society and continued to be its President till his death in 1794.

Objects

The objects of the Asiatic Society were stated in an ornate style by William Jones in his opening address as follows: 'You will investigate whatever is rare in the stupendous fabric of nature, will correct the geography of Asia by new observations and discoveries, will trace the animals, and even traditions, of those nations, who from time to time have peopled or desolated it; and will bring to light their various forms of government, with their institutions, civil and religious; and you will examine their improvements and methods in arithmetic and geometry, in trigonometry, mensuration, mechanics, politics, astronomy and general physics; their skill in surgery and medicine and their advancement, whatever may be in anatomy and chemistry. To this you will add researches into their agriculture, manufactures and trade, and whilst you enquire into their music, architecture, painting and pottery. You will not neglect those inferior arts, by which comforts, and even elegances of social life, are supplied or improved.'[b]

Indeed the canvas of investigations was wide; for not only did it embrace the letters, sciences and arts, the inanimate rocks and the animate

[a] Mitra, p. 3.

[b] Mitra, pp. 4–5.

fauna and flora but even covered a wide range of human thinking and reflections. In fact Jones himself said: 'If now it be asked, what are the intended objects of the enquires within these spacious limits, we answer: Man and Nature—whatever is performed by the one and produced by the other within the geographical limits of Asia.'

William Jones

William Jones himself set an example in this direction. He became well versed in Sanskrit and threw fresh light on the antiquity of the Indian Zodiac, the lunar year of the Hindus, the Hindu chronology, Indian plants, etc. He prepared a catalogue of the Indian plants with their names both in Sanskrit and Linnaean generic nomenclature. To perpetuate the botanical interests of William Jones, Roxburgh established the genus *Jonesia* Roxb. (Sarca L.). A man of deep culture, William Jones did signal service to the furtherance of oriental and scientific pursuits in India by establishing the Asiatic Society. He died at an early age of forty-eight in 1794. During his stay in India, short as it was for about ten years, the Asiatic Society steadily progressed towards its becoming a premier society of its type in Asia. There was no Indian as member of the Society when it started. However, now and then, papers written by Indians used to be presented. In April 1785, a paper in Persian entitled 'The Care of the Elephantiasis and other Disorders of the Blood', written by a Muhammadan medical man, was translated into English by Jones himself and presented by him to the Society. It was only in 1829 that a few Indians were elected as members of the Society for the first time.

The Asiatic Society had no building of its own for twenty-four years. As long as Jones was alive, the meetings were held in the Grand Jury Room of the old Supreme Court. It was only in 1808 that the Society was able to function in its own building on Park Street in Calcutta.

For a long time the East India Company was primarily concerned with the manufactures and the produce typically Indian. Nevertheless, when it consolidated its political position in the later half of the eighteenth century, the Company found it prudent to have a few scientific and technical establishments like the Survey Department and the Botanical Gardens as pointed out earlier. But it did not promote or organize studies of the natural history of India on scientific lines. However, the naturalist-members of the Asiatic Society were greatly interested in investigations of the rich and varied fauna and flora as well as geology and geography of India, and the Society encouraged such investigations.

EDUCATION

The East India Company for long was concerned mainly with its commercial interests and hence chose to be indifferent towards the promotion of education of the people of India as one of its distant objectives even.

In the last two decades of the eighteenth century, however, some efforts were made for establishing a few educational institutions. Governor-General Warren Hastings founded in 1781 a *Madrassa* at Calcutta by providing a building for it at his own expense which was afterwards charged to the Company. The object of this institution was to promote the study of the Arabic and Persian languages and the Muhammadan Law, with a view, more especially, to the production of well-qualified officers for the Courts of Justice.[a] Nevertheless, in later years the curriculum underwent some change by including courses in natural philosophy, astronomy, geometry, arithmetic, logic and rhetoric. But it must be noted that the English language was not introduced as one of the subjects of study, nor was western learning taught there. In 1791 Jonathan Duncan, the Resident at Banares, opened the Hindu College with the object of educating the Hindus in their own language by prescribing courses in theology, medicine, music, mechanics, arts, grammar, mathematics, history, philosophy, law and literature.

Of considerable historical significance from the point of view of the introduction of English education in India, is the active interest evinced by one of the Directors of the East India Company, Charles Grant who wrote a treatise (1792–97) entitled *Observations on the State of Society among the Asiatic Subjects of Great Britain, Particularly with Respect to Morals; and on the Means of Improving It.* Even though in this treatise Grant made some devastating remarks, many of them being in the nature of half-truths, he entered a vigorous plea to impart western education to the Indians in English, failing which in the Indian languages themselves. In his treatise he wrote: 'Perhaps, no acquisition in natural philosophy would so effectively enlighten the mass of people, as the introduction of the principles of mechanics and their application to agriculture and the useful arts. Not that the *Hindoos* are wholly destitute of simple mechanical contrivances. Some manufactures, which depend upon patient attention and delicacy of hand, are carried to a considerable degree of perfection among them; but for a series of ages, perhaps for two thousand years, they do not appear to have made any considerable addition to the arts of life. Invention seems wholly trepid among them; in a few things they have improved by their intercourse with Europeans, of whose immense superiority they are at length convinced; but this effect is partial, and not discernible in the bulk of the people. The scope for improvement, in this respect, is prodigious.' Further, he advocated the improvement in agriculture by the introduction of mechanical contrivances.[b] However, as it happened, the introduction as well as the growth of English education and, as part of it, the scientific and technical education could take roots in India only in the nineteenth century.

[a] Mahmood, pp. 18–19.

[b] Mahmood, pp. 17–18.

SCIENCE AND SCIENTIFIC ORGANIZATIONS IN THE NINETEENTH CENTURY

In the history of the people of India the importance of the nineteenth century which witnessed intellectual, economic and social development of a new order heralding the dawn of the modern outlook need hardly be overemphasized. It has been rightly said: 'The nineteenth century was the great dividing line, and these hundred years changed the face of India far more than did the preceding thousand years.'[a] Evidently, the elements of the civilization of the West, the spirit of rationalism and the new awakening which burst forth in Europe then began to produce, albeit in a restricted way, a noticeable impact upon the minds of the Indians. Perhaps it is no exaggeration to say that one of the main causes for this development was the introduction of English education which, despite its outlandish incongruity and being limited to certain sections of the people, contributed significantly to the transformation of India particularly in the later half of the nineteenth century. It may be noted that the first five universities were founded at Calcutta, Bombay, Madras, Allahabad and Lahore, and a number of technical or professional schools and colleges established in different parts of the country during this period. Further, the provincial governments recognized the education of the people as one of their utmost responsibilities and constituted departments of public instruction for this purpose.

The later half of the nineteenth century also saw the introduction of the telegraph and the railways. The first section of the telegraphic line was completed in February 1851 near Calcutta between Alipore and Rajghat, a distance of some 15 miles. The line was of iron rod $\frac{3}{8}''$ in diameter weighing about 1,940 pounds per mile, in separate lengths of 13′ 6″, each welded together and with a protective coating of cloth and pitch so as to form a pliable envelope which would be impervious to water, saline, earth and eroding organisms.[b] This work was accomplished by W. B. O'Shaughnessy, a medical man who was then Professor of Chemistry in the Medical College at Calcutta and who later became the first Director of Telegraphs in India. He covered a further distance of 24 miles of telegraph line from Calcutta in the direction of Diamond Harbour by November 1857. It is interesting to note that in the same year Samuel Morse connected Washington with Baltimore, a distance of about 40 miles, with his device. An Indian by name Shib Chandra Nandy was associated with the work of O'Shaughnessy and was largely responsible for the laying of about 900 miles of telegraphic lines from Barakar to Allahabad, Banares to Mirzapur and onwards, and from Calcutta to Dacca. In the course of the next six years there were over 4,500 miles of telegraphic lines in India and some 46 receiving stations.[c]

[a] Majumdar (R. C.), X, pt. 2, p. 95.
[b] W. B. O'Shaughnessy's Report preserved in the Victoria Memorial, Calcutta.
[c] Das Gupta (A. P.), p. 30.

The first railway line was laid in 1853 between Bombay and Thana covering a distance of about 20 miles. In the next fifteen years the length covered by the railways rose to 1,088 miles, and by 1871 it was 5,077 miles. There was indeed a rapid advance in railway construction and by the end of the century, i.e. in the next span of about 30 years, 24,760 miles of railways were laid,[a] connecting the important towns, harbours, and coal and other mineral-producing areas. In fact, the railway enterprise in India received from the government rather an extraordinary encouragement in preference to the construction of canals for irrigation purposes, as the former proved to be an effective carrier of goods of commercial importance in furtherance of the enlightened self-interest of the British. Whatever might have been the reason, the notable fact was that the railways created new types of employment, trade marts, new townships and introduced an element of mobility and intercourse among the different sections of the people, with obvious impact on certain social changes even.

Apart from the telegraph and the railway, it may be noted that, as a result of the military and commercial motives on the one hand and administrative exigencies which cropped up from time to time on the other, the government had to adopt concerted measures for making the then existing scientific service organizations more broad-based and utilitarian, as also establishing some new scientific institutions. Thus, among others, the meteorological, survey and botanical organizations developed all-India character; the geological survey came into being; and research institutes in engineering, bacteriology, medicine and agriculture were established. All these had impact, in their respective spheres, on the political and economic life of the nation. The network of scientific institutions of necessity spread over different parts of the country, and the gradual involvement of some of the local inhabitants in the scientific investigations, produced not unnoticeably a scientific climate in the country. Added to this, the learned societies took the lead not only in supporting a number of investigations but also publishing in their transactions and journals the important scientific findings of the investigators, some of whom travelled far and wide, on the plains and the hills, in pursuit of their researches. Though the people as a whole could not admittedly imbibe the true scientific spirit and were not educated enough to appreciate the importance of the scientific efforts, they could not but witness the growing influence of western science and its gradually taking roots in India.

ROLE OF THE ASIATIC SOCIETY AND OTHER LEARNED BODIES

Of the learned societies, the Asiatic Society continued to play a key role. As stated before, the Society moved to its own building in Park Street, Calcutta, in 1808. In the same year, Hare, a member of the Society, moved 'that a Committee be appointed for the purpose of physical

[a] Dutt (R. C.), p. 548.

investigations, the collection of facts, specimens, and correspondence with individuals whose situations in the country may be favourable for such discussions and investigations,'[a] and subsequently recommended the formation of two Committees—one for 'Natural History, Physics, Medicine, Improvement of the Arts, and whatever is comprehended in the general term of Physics', and the other for Literature. From 1818 onwards the Physical Commitee did active work for several years. The biological as well as geological science also received necessary attention. The naturalist members of the Asiatic Society were greatly interested in scientific investigations of the rich and varied flora and fauna as well as geology and geography of India. Among the earlier members of the Society were a number of mathematicians with the result the scientific contributions received in the beginning by the Society were concerned with some branch or other of mathematics.[b] As to the publications by the Society of research papers, the *Asiatick Researches*[c] was divided into two parts in 1829—one devoted wholly to scientific papers, and the other to literary communications. In 1832, the Society started publishing the *Journal of the Asiatic Society*[d] which, though in the beginning was devoted to the publication of papers of literary character, was an important periodical for scientific communications. In a period of about fifty years over 500 papers in mathematical and physical sciences, 560 in zoology, 320 in geology and 80 in botany, besides some scientific notices, found place in this *Journal.* Besides the Asiatic Society, the Agricultural Society of India founded by William Carey in 1820 (renamed in 1826, the Agricultural and Horticultural Society of India) and the Bombay Natural History Society (1848) were among the other learned bodies which provided stimulus to scientific pursuits.

It may, nevertheless, be emphasized that the founding of scientific organizations and learned societies was largely inspired by similar institutions in Britain. No wonder that the organizational structure and even the aims and objective of some of them had their parallels in Britain. All the same, the men of science, though of European origin, who ushered in and nurtured these institutions spared no efforts in promoting them in the Indian context. In the latter half of the nineteenth century, the Indians who also began to work with them not only imbibed the spirit of free inquiry but also acquired experimental skills. Such an impact on the investigations undertaken by the Indians was discernible to a marked extent towards the closing of two decades of the century.

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[a] Mitra, pp. 15—16.

[b] Bose (P. N.) (1), p. 8.

[c] The publication ceased in 1839.

[d] In 1829 Captain J. D. Herbert, Deputy Surveyor-General, started a monthly under the name *Gleanings in Science* with a view to publishing extracts and abstracts from the European scientific publications. It used to publish also the Society's monthly proceedings. On the initiative of James Prinsep, one of the Secretaries of the Asiatic Society, the periodical was taken over by the Society, and published under the name *The Journal of the Asiatic Society,* though the first number bore the title *Journal of the Asiatic Society of Bengal.*

The researches conducted in India in the nineteenth century encompassed different branches of science and received support from several scientific organizations. A significant feature was the use of instruments, some obtained from Britain and others designed and fabricated in the country itself. There were makers of scientific instruments at Calcutta, Bombay, Madras and Bangalore. A few of them were Indians, too, who soon learnt the instrumentation technique and were able to produce even some complicated instruments needed for survey work and engineering. Truly the modern science and technique made inroads into India in the nineteenth century. The following is in the nature of highlighting the major scientific organizations and researches, and the growth of scientific and technical education in India during this period.

PHYSICAL SCIENCE INCLUDING METEOROLOGY, ASTRONOMY, SOLAR AND TERRESTRIAL PHYSICS

Meteorology

In the nineteenth century the meteorological and allied observations necessarily continued to make headway and became widespread in several parts of the country.[a, b] At Calcutta, James Kyd prepared the register of tidal observations (1805–1828) relating to day and night tides in the river Hooghly at Kidderpore. G. T. Hardwicke maintained a meteorological register at Dum Dum from 1816 to 1823. In 1823 James Prinsep took a series of meteorological observations at Banaras for two years. In addition, he studied the wet-bulb indications and contributed a paper on the depression of the wet-bulb hygrometer.[c] He also analysed the daily range of the barometer in different parts of India. Major J. T. Boileu prepared tables for determining the elastic force of aqueous vapour in the atmosphere as well as the dew-point temperature.[d] In 1835, R. Everest published a paper on the revolution of the seasons, as also on the correspondence between the atmospheric phenomena and the changes of the moon.[e] He gave a detailed account of rain and drought of eight seasons in India from 1831 to 1838. There were others like Cunningham, Richard Stratchey and Royle who meticulously recorded the meteorological data of their stations, some of which were at high altitudes. The diverse meteorological observations were also classified and studied from time to time, particularly at the Surveyor-General's office. It was in 1848 that the first attempt was made to record the maxima and minima temperatures, and in 1856 hourly observations were started.[f] H. Piddington, who was the Curator of the Museum of Economic Geology and President of the Marine Court of Enquiry, compiled a series of 23 memoirs on the law of storms.

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[a] Bose (P. N.) (1), pp. 10–11.
[b] Markham, pp. 275–310.
[c] Prinsep, pp. 396–432 and 828.
[d] Boileu, pp. 135–70.
[e] Everest (2), pp. 345 and 631.
[f] Markham, p. 278.

His account of the important cyclones[a] which occurred in the East from 1829 to 1857 is well known.

In the south, as early as 1836, the Rajah of Travancore founded at Trivandrum an observatory in which extensive observations were recorded by John Allan Broun, astronomer to the Rajah, from 1852 onwards. A branch of this observatory was also established in 1855 at Agastya-mula (a peak 6,200 ft. high), and the hourly observations made there yielded valuable data on atmospheric pressure, temperature, humidity and evaporation. Meteorological observations were also in progress by medical men and army officers at Bangalore, Mysore, Coorg, Doddabetta on the Nilgiri hills (8,640 ft. high) and Sikandarabad.[b]

In the west, Benjamin, Norton and Colonel Sykes were the leading meteorologists. In particular, Sykes not only brought out the outstanding features of his barometrical indications relating to diurnal and nocturnal tides but also analysed systematically his hygrometric observations. He described the spectacular circular and white rainbows in the Deccan, the peculiarity of the winds, frequency of calms, quantity of electricity in the atmosphere and the peculiar atmospheric opacity in hot weather.[c] The Bombay Observatory, established in 1823, made valuable contributions to meteorology from 1842 onwards, under George Buist, Orlebar, Montriou, Fergusson, Morland and Chambers.

Though the meteorological stations in different parts of the country were actively engaged in the collection of valuable data, the need was felt for a general system of meteorological observations on a uniform plan. In 1863, Thomas Glaisher prepared a report pleading for such a recourse. Perhaps the year 1864 is of considerable significance in the history of meteorology in India; for in that year occurred a major cyclone which gripped Calcutta and the neighbourhood with devastating consequences—loss of over 80,000 human lives and huge damage to property on land, and ships on the sea. The Bengal Famine of 1866 was another natural calamity which further necessitated the development of meteorological observations.

In 1865 a meteorological committee was appointed at Calcutta 'to consider the best means of establishing a system of observations for the protection of that port'.[d] The committee recommended the appointment of observers, who were assistants in the Electric Telegraph Department, to record the data and transmit them by telegraph to the meteorological observatory attached to the Surveyor-General's office at Calcutta. Soon meteorological reporters were appointed to the Governments of the Panjab (A. Neil) and the North-West Provinces (Murray Thomson). In 1867, H. F. Blanford, who was then Professor of Natural Sciences at the Presidency College at Calcutta and who was to play a great role in the evolution of the meteorological department, to be noticed later, was appointed as Meteorological Reporter to the Government of Bengal.

[a] The term cyclone was coined by Piddington, based on the Greek word *Kuklos* which connotes the coil of a snake.

[b] Markham, pp. 281–83.

[c] Markham, pp. 285 and 288–89.

[d] Markham, p. 291.

Though the work done by the different meteorological stations was indeed considerable and useful, the necessity arose for establishing observatories in select parts of the country. Between 1865 and 1871, such observatories were established, and their work comprised collection as well as recording of the atmospheric data, issuance of cyclone warnings well in advance, tidal observations and astronomical and magnetic studies. The Alipore Observatory at Calcutta was also determining correct time for the benefit of ships and telegraph offices by recording transit observations of stars. Of the important instruments in use then, mention may be made of Osler's self-registering anemometer, different types of thermometers, Newman's standard barometer, Regnault's hygrometer, pluviometer, electroscopic apparatus and tide gauge.

Blanford and the Meteorological Department

Organizationally the time had come to conceive of an all-India meteorological institution. In 1875, the India Meteorological Department was established with a view to consolidating the work of the provincial organizations. The chief functions of the department included then, as now, experimental observations, preparation of daily weather charts, issuing weather summaries, seismological studies, solar physics and terrestrial magnetic studies. In 1875, Blanford was appointed as Meteorological Reporter to the Government of India. Under his able guidance the Meteorological Department registered rapid progress, for Blanford not only reorganized the department but also sought to raise the number of observatories so as to have an all-India coverage. He took concerted measures for improving upon the quality of observations leading to effective coordination of the data collected. By 1878 there were as many as 103 observatories at work, and in 1885 their number rose to 128, exclusive of 22 observatories in Bengal, which were established in connection with the provincial system of collecting telegraphic weather reports.[a]

Realizing the importance of collecting data concerning the forest weather, Blanford established in 1885 an observatory at the Forest School at Dehra Dun, which also served as a training institution.[b] To Blanford, therefore, belongs the credit of being practically the founder of systematic and uniform meteorological observations through the length and breadth of India.[c]

Blanford himself was a great experimentalist and a meticulous compiler of the observed data. He showed that the variations in solar heat, being considerable, would exert an influence on all the terrestrial phenomena, and stressed the need for direct actinometric observations as the only means of ascertaining the heat-variation.[d] He made observations on the irregularities of atmospheric pressure in the Indian monsoon region. In addition, he worked on the variations in the barometric tides with reference

[a] Black, pp. 283–96.
[b] Black, p. 298.
[c] Bose (P. N.) (1), pp. 12–13.
[d] Markham, p. 307.

to diurnal land and sea breezes. He also prepared a catalogue of the recorded cyclones in the Bay of Bengal up to the end of 1876. With John Eliot, Blanford made significant contributions relating to rainfall, tornadoes, hygrometer and the like.

FIG. 10.1. Sketch of the Weather Chart of India: 16 Sept. 1888. (Reproduced from *Regional Meteorological Centre, Nagpur, Silver Jubilee Souvenir*, Appendix III.)

In 1878, Eliot introduced a system of daily reports on the weather in all parts of India.[a] He even devised a system of issuing storm signals for the port. It would appear that before 1884 all the officers of the India Meteorological Department were Europeans. In 1884, however, the department took a decision to train an educated Indian, as an experimental measure, in meteorology, particularly in the preparation of daily weather reports. This honour fell on Lala Ruchi Ram Sahni of the Panjab, who, after his B.A. degree in physical science, was then qualifying for M.A. degree.[b] In 1889, Eliot succeeded Blanford as the Meteorological Reporter to the Government of India.

[a] Black, p. 293.

[b] Black, p. 297.

Astronomical Investigations

In respect of astronomical investigations, there were some individual attempts to observe the transit of planets like Mercury and Venus. James Prinsep observed the transit of Mercury on the 5th of May 1832 using a four-foot achromatic telescope of four inches aperture, mounted equatorially and provided with a delicate micrometer.[a] Colonel Tennant made observations on the transit of Venus, and its egress from the sun, on the 9th of December 1874 at Roorkee.[b] These individual efforts amply illustrate the versatility of the persons concerned, and their abiding interest in matters celestial.

At the Madras Observatory important astronomical work was in progress, a summary of which can be found in Markham's book. Briefly stated, John Goldingham and his deputy Warren, both trained astronomers, were engaged in many an astronomical observation. In their work they were ably helped by two Indian assistants who made regular astronomical observations relating to the sun's transit every day at noon, the eclipse of the Jupiter's satellites occurring almost every night, and the transits of a number of recognized stars, with a view to regulating the astronomical clock. Thomas Glanville Taylor, who succeeded Goldingham, equipped the observatory with new and more powerful instruments including transit instruments, astronomical clocks, telescopes and circular measurer.[c] He began the compilation of the *Star Catalogue* which was published in 1844 in its final form containing the places of some 11,000 stars.[d]

N. R. Pogson, who was associated with this observatory for a period of thirty years (1861–1891), equipped it with precision instruments, the principal among them were a transit circle and an 8½-inch equatorial. The former was employed for the preparation of a catalogue of 5,000 stars. With the latter Pogson discovered six minor planets and seven variable stars. The minor planets, noticed between the orbits of Mars and Jupiter, were *Asia* (17 April 1861), *Freia* (2 February 1864), *Sappho* (3 May 1864), *Sylvia* (16 May 1866), *Camilla* (17 November 1868) and *Vera* (6 February 1885).[e] It was Pogson who thought of establishing a branch of this observatory in the Palni or Nilgiri hills, particularly for the photographic and spectroscopic observations of the sun and the stars. But no action ensued in his lifetime. The Madras Famine of 1876–1877 which occurred due to the failure of the moonsoon rains gave a fillip to the establishment of a solar physics observatory, inasmuch as the Commission of Inquiry which was appointed by the government to investigate the cause of the famine, brought to the notice of the government 'a correlation between the seasonal distribution of rain in India and sunspot periodicity and hence recommended

[a] Bose (P. N.) (1), p. 10.
[b] Bose (P. N.) (1), p. 18.
[c] Phillimore, II, pp. 195–96; Markham, p. 329.
[d] *Regional Meteorological Centre, Madras*, pp. 2–4
[e] Black, pp. 312–13; Markham, pp. 333–34.

that necessary steps be taken for solar observations'.[a] When C. Michie Smith was appointed as Government Astronomer to succeed Pogson in 1891, the project began to take some shape. In 1895, Michie Smith selected Kodaikanal in the upper Palni hills as the location for establishing a solar physics observatory. The construction work was taken up in 1899 and in the same year the administrative control of this observatory was transferred to the India Meteorological Department. The Solar Physics Observatory started functioning in 1900. Sunspot spectra, hydrogen content of solar prominences, spectrum of the night sky, variation in the area of hydrogen absorption, and meteorological and seismological studies were among the important investigations undertaken in this observatory.

Geomagnetic Studies

In respect of geomagnetic studies, as early as 1834 India participated in the global study of the earth's magnetism, which was organized by the Göttingen Magnetic Union with a view to recording simultaneous magnetic observations at 50 stations during 1834–1841.[b] Out of the six stations in the whole of Asia selected for this purpose, there were three in India—at Madras, Simla and Trivandrum. Later in 1840, a magnetic observatory was started at Colaba (Bombay) through a fortunate accident. In that year, a magnetic observatory was proposed to be started at Aden and as for some reasons it was not materializing then, the instruments were diverted to Colaba where a meteorological and time determination observatory had already been at work since 1823. The magnetic observatory was shifted from Colaba to Alibag (18 miles south-east of Bombay) in 1904, in view of the introduction of the electric traction for the street tram service then, lest the electric current should vitiate the magnetic observations. The Alibag Observatory is regarded as one of the primary magnetic observatories of the world.

Isostasy

In the field of geophysics, the officers of the Trigonometric Survey of India continued to provide the lead. In 1864, the Surveyor-General Walker applied to the Secretary of State for India, seeking permission to undertake a series of pendulum experiments in connection with the trigonometrical survey. The proposal found the support of most of the eminent Fellows of the Royal Society which, for this purpose, even lent an astronomical clock and two invariable pendulums which were supplemented by a copper vacuum cylinder and an air pump. Captain J. P. Basevi,[c] who was entrusted with this task, did experiments at nineteen stations of the Indian Arc from Dehra Dun to Cape Comorin, in addition to two stations

[a] *Kodaikanal Observatory*, p. 2.
[b] *Alibag Observatory*, p. 3.
[c] Basevi, pp. 251–72; *Professional Papers*, III, pp. 97–108; 199–208.

on the east coast, and two on the west coast as also in the Minicoy Island. The Imperial Academy of Sciences at St. Petersburg lent two convertible pendulums (which were already used on the Russian Arc) with a view to establishing a connection between the Indian and the Russian experiments. These investigations led to the important discovery of isostasy, i.e. a condition supposed to exist in the earth's crust, whereby equal earth masses underlie equal areas down to an assumed level of compensation. These were interpreted mathematically by A. Pratt, as a result of which the theory of isostatic compensation emerged.[a]

Other Physical Investigations

O'Shaughnessy who, as stated before, was the first to conceive of and lay the telegraphic line, contributed several memoranda based on his electric experiments relating to the communication of telegraphic signals by induced electricity.[b] Schwendler, who held the post of Superintendent Electrician of Government Telegraphs in India, conducted experiments on the use of platinum for the emission of brilliant light when a sufficiently strong electric current was passed through it. He also investigated the proper method of supplying signalling currents.[c] Major Waterhouse of the Survey of India examined the influence of the newly discovered dye called eosin, on the photographic action of the solar spectrum upon the bromide and bromide-iodide of silver. Another work for which he is well known related to the photographs of the solar disc which he took in connection with the transit of Venus in December 1874.[d]

SURVEY OF INDIA

In the nineteenth century the survey work assumed a new dimension and was carried out in a truly scientific manner using a number of instruments which included the theodolite, chronometer, telescope, prismatic compass, perambulators, planetables and sextants. The surveyors were able and devoted men among whom the names of William Lambton and George Everest stand out prominently.

William Lambton

In the history of the Survey of India the name of William Lambton (1753–1823) has particularly a distinct place. For it was Lambton who initiated a progressive survey of the whole country and ushered in the Great Trigonometrical Survey of India. In brief, the trigonometrical surveying is divided into three distinct branches.[e] *Firstly*, some sites are selected for measuring base lines so as to form the ends of certain ranges

[a] Pratt (1), pp. 310–16; Pratt (2), pp. 34–24.
[b] Bose (P. N.) (1), pp. 15–16.
[c] Bose (P. N.) (1), pp. 16–17.
[d] Bose (P. N.) (1), pp. 18–19.
[e] Markham, p. 61.

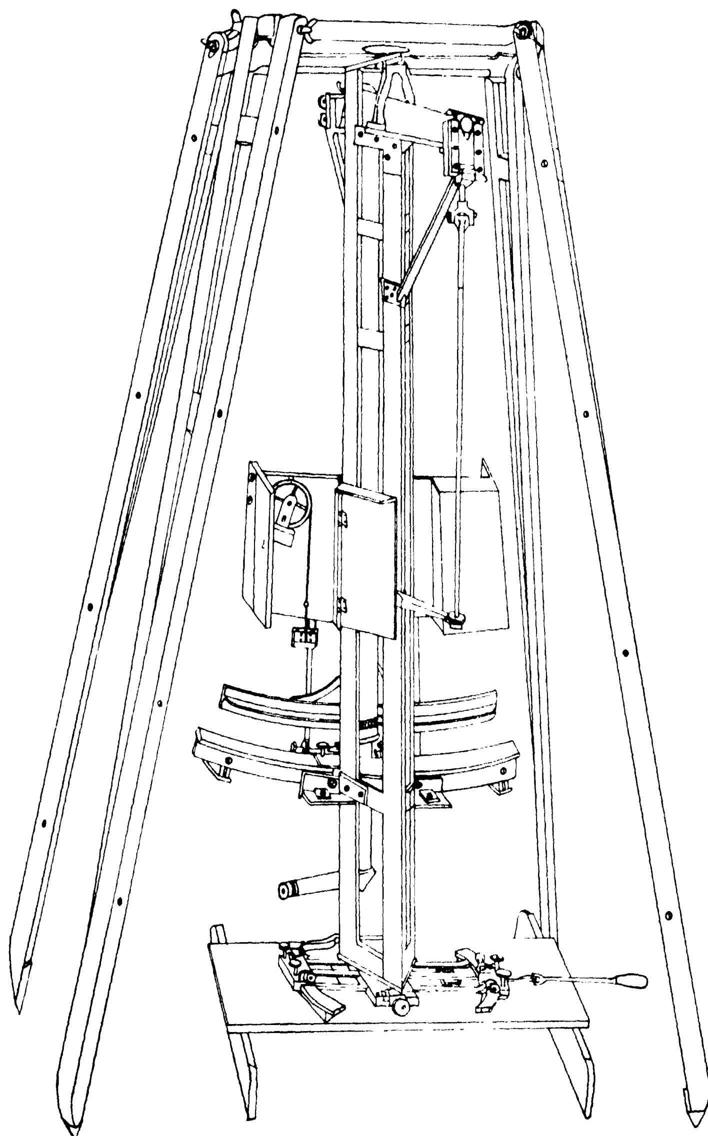


FIG. 10.2. Sketch of the Zenith Sector used by William Lambton, now preserved in the Victoria Memorial Museum, Calcutta. (Courtesy, Sri S. N. Sen who got the sketch made in connection with the *Inventory of Scientific Instruments of Historical Importance*, now under preparation by him.)

of triangles which are then measured as accurately as possible. The base of the triangle is computed, and by trigonometrical methods, the distances of other points visible from its extremities are ascertained through angular observations with the help of suitable instruments. *Secondly*, the desired range of triangles is constructed by determining the positions of selected points on the earth's surface by the angles taken from the ends of the measured base line, and then carried on from point to point in succession so as to form a network of positions along a belt of the country. Then the primary triangulation is completed by a specific number of such belts across the desired area of survey in the directions of both latitude and longitude. *Thirdly*, the triangulation so done is checked by astronomical observations of latitude and longitude at selected points.

Lambton was well versed in trigonometrical computations, geography and geodesy. The experience of his military service convinced him of the need of employing the geodetic methods which would help determine the size and figure of the earth's surface through determinations of triangulation, altitude, longitude and gravity. Lambton's efforts for a scientific mapping of India using the geodetic science received great support and warm appreciation from the government. Encouraged by this, he had already proposed in the closing year of the eighteenth century, a mathematical and geographical survey across the peninsula from coast to coast, which 'was to serve as a foundation for a general survey of the whole country, being controlled by astronomical observations and carried out on scientific principles, and was to be capable of extension in any direction and to any distance.'[a, b]

In 1800, an independent trigonometrical survey was organized in Madras. Lambton commenced his task in Mysore area, measured a base line near Bangalore, and in the next eighteen months carried out a preliminary triangulation of Mysore. In his earlier attempts Lambton used a chain of blistered steel consisting of forty links of two and a half feet each with a total measurement of 100 feet. He had also in his possession one three-foot theodolite, one circular instrument, one zenith sector, a small transit telescope, two steel chains, six thermometers, one astronomical telescope and two small chronometers, with which he carried out his subsequent work. As the first operation of his general trigonometrical survey, he measured a base line near St. Thomas Mount at Madras for his triangles north and south through the Carnatic. He then completed a meridional arc from Cuddalore to Madras and by observations of latitude at both ends he was able to attain a value of the degree for his work. By 1815 he had compiled a general map of the southern region. Further, he determined the largest arc ever measured in any other country, having an amplitude of 9° 53′ 45″ and so close to the equator.[c] Lambton's efforts resulted not only in covering the entire peninsula as high as 15° N. lat. with a network of triangles, braced by main cross belts and but also in fixing the geographical position of a number of prominent points. His results

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[a] Markham, pp. 63 ff. [b] Phillimore, II, p. 3. [c] Bose (P. N.) (1), p. 4.

were published 'with such explanations and discussions that proclaimed to the whole scientific world that a survey was proceeding in India that would yield geodetic results of the very highest importance to science.'[a]

Lambton's systematic work earned him a permanent place in the field of geodetic measurements. As General Walker said of him later (1870): 'Of all Colonel Lambton's contributions to geodesy, the most important are his measurements of meridional arcs, the results of which have been employed up to the present time, in combination with those of other parts of the globe, in all investigations of the figure of the earth.' What is more, Lambton produced a profound impact upon his flagmen who were Indians. In the words of Everest who collaborated with him: 'I learnt how to value the natives of southern India, who, knowing no master but Lieutenant-Colonel Lambton, unconnected with and unknown by the government they served, without provision for themselves in case of their being crippled by sickness, accident or age, or for their families in the event of their death, yet ventured fearlessly and without a murmur to face those awful dangers which would have made the stoutest hearts quirl and shrink.'[b] Such then was Lambton whose qualities of head and heart were a great source of inspiration to his followers. As to Lambton himself, he wrote in one of his reports thus: 'In 20 years devoted to this work I have scarcely experienced a heavy hour. Such is the case when the human mind is absorbed in pursuits that call its powers into action. A man so engaged, his time passes on insensibly, and if his efforts are successful his reward is great, and a retrospect of his labours will afford him an endless satisfaction. If such should be my lot I shall close my career with heartfelt satisfaction, and look back with unceasing delight on the years I have passed in India.'[c]

Lambton had two technical assistants, Henry Voysey as surgeon and geologist of whom we shall speak later, and George Everest as surveyor. Soon he extended his great work and carried his central arc northwards into Berar before he breathed his last on his way to Nagpur in 1823. His work was continued with equal precision by Everest in Upper India. There is no denying that both Lambton and Everest contributed a great deal to the geodetic mapping of India on scientific lines.

Mackenzie and others

In 1815, Mackenzie[d] was named the Surveyor-General of India with the object of controlling the surveys of the three Presidencies, but he did not have any authority over the survey work in progress under Lambton. In 1818, however, Lambton's work, which by then had reached beyond the limits of the Madras Presidency, came under the over-all control of the government under the name 'The Great Trigonometrical Survey of India'.

[a] Phillimore, II, p. 4.
[b] Phillimore, III, p. 396.
[c] Markham, p. 69.
[d] Markham, pp. 73 ff.

Even though appointed as the Surveyor-General of India, Mackenzie chose to remain in the Madras Presidency for two years, reorganized the department effectively and, on his own part, started the survey of the then Northern Circars with the help of his assistants, William Scott, Henry Hamilton and Marcellus Burke. This survey, later designated as the 'Rajamundry Survey', was completed in 1824 with full details by using plain-table, angular instruments and field-books.

In 1822, it was decided to prepare an atlas of India so as to depict the whole country on the quarter-inch scale, and for this purpose selections were made from the different surveys and suitably reduced. These constituted the standard map of India for the next eighty years.

The survey of the Himalayas was also taken up in right earnest by John Anthony Hodgson who is well known for his survey of Sirmur and Garhwal (1816-1818), making the Chaur peak as his principal station of observation. Early in 1817, William Spencer Webb started an independent survey of the Kumaon hills and completed his work in 1821. The survey up the river Brahmaputra was also undertaken at this time. Hodgson became the Surveyor-General of India (1821) and initiated revenue survey of Upper Provinces one by one. He even held charge as Revenue Surveyor-General from 1823 to 1826. Valentine Blacker who produced important maps of Central India was Surveyor-General from 1823 to 1826.

In the Bombay region, while James Southerland took up a regular survey of the Deccan (1810), Thomas Jervis started an independent survey of the southern Konkan, though both these surveys seemed to lack the desired accuracy.

George Everest

Special mention has been made already of George Everest who made conspicuous contributions to the Survey of India. In 1824, he continued the Great Arc of triangulation across the Narmada to Sirnoj (on parallel 24°). But on account of ill health he returned to England, and six years later was again in India with the most up-to-date instruments that he could obtain in Great Britain to carry on the trigonometrical survey. His new instruments included compensation bars (instead of the chains), a large theodolite with an azimuth circle of 36″ diameter, two double vertical circles (three feet in diameter; for astronomical observations), heliotropes and reverberatory lamps.

In October 1830, Everest was appointed as the Surveyor-General of India as well as Superintendent of the Great Trigonometrical Survey, and he occupied this high office for about 13 years. It may be said without exaggeration that this period was by far the most important in the progress of geodetic work in India, and the man solely responsible, not only for the organization of the survey work but also for the achievements of high order, was undoubtedly Everest. With great ability and imagination, he evolved a working plan for the trigonometric survey, recruited and

trained the staff for his purpose and, more importantly, secured in an abundant measure the goodwill and support of the government at home and the Court of Directors in England. In his arduous task, he was ably assisted by Andrew Scott Waugh, a surveyor of the highest calibre, who befittingly succeeded him as Surveyor-General in 1843. Of the other loyal assistants, Renny, Wilcox, Boileu, Logan, Oliver, Murphy, Armstrong and James proved eminently fit for field-work. As to the instruments, he had already in his possession, as stated above, the most accurate and useful ones. Imaginative as he doubtless was, he managed to get one Henry Barrow, a skilled mechanic, from London as mathematical instrument maker. Even so he had already observed an Indian, Mohsin Husain of Arcot in south India, who proved his mettle in mechanical repairs and adjustments, and reconstruction of old instruments. Husain even accompanied Everest in some of the surveys and impressed him as a remarkable mechanic with inventive talents. Of him Everest said: 'He has both genius and originality; his conduct is marked by the highest probity, and he is one of the few on whose word I could place entire reliance.'[a] When Barrow gave up the job and left for home, Everest appointed Husain as the mathematical instrument maker at Calcutta. For his ingenuity, Husain was granted a personal allowance of Rs.150 per month even after Everest left.

For his projected work, Everest organized two field and six subordinate meridional series, and kept one field party under his own charge. Between 1832 and 1841, all the field-work of Everest's two sections of the Great Arc from Bidar in the then Nizam's territories to Banog in the Himalayas—a direct distance of about 870 miles, from the latitude 17° 55′ to 30° 29′—was completed. As regards the six subordinate meridional series, he was able to complete three of them, viz. Budaon, Rangheer and Amua (central India, near Sagar), whilst the other three, viz. Karara, Chindwar and Gora, were in progress.

Andrew Waugh

Andrew Waugh, who was born in Cannanore (Kerala) and who later worked intimately with Everest, took up the triangulation of the region between the Great Arc series and Calcutta, and completed it with great accuracy. He then proceeded with the north-eastern Himalayan series in 1845 and brought it to a successful conclusion in 1850. It is interesting to note that this was the largest series in the world at that time, being some 1,690 miles long from the Dehra Dun base to that of Somakhoda, in the Purnea district of Bengal. While the main chain of this series was in progress, the heights of the major Himalayan peaks were fixed using a theodolite. Of the 79 peaks so determined, the highest called the 15th peak, which was 29,002 feet above sea-level, was named as Mount Everest by Waugh, in honour of George Everest.[b]

[a] Phillimore, III, p. 458.

[b] *Cyclopaedia of India*, III, pp. 80–81.

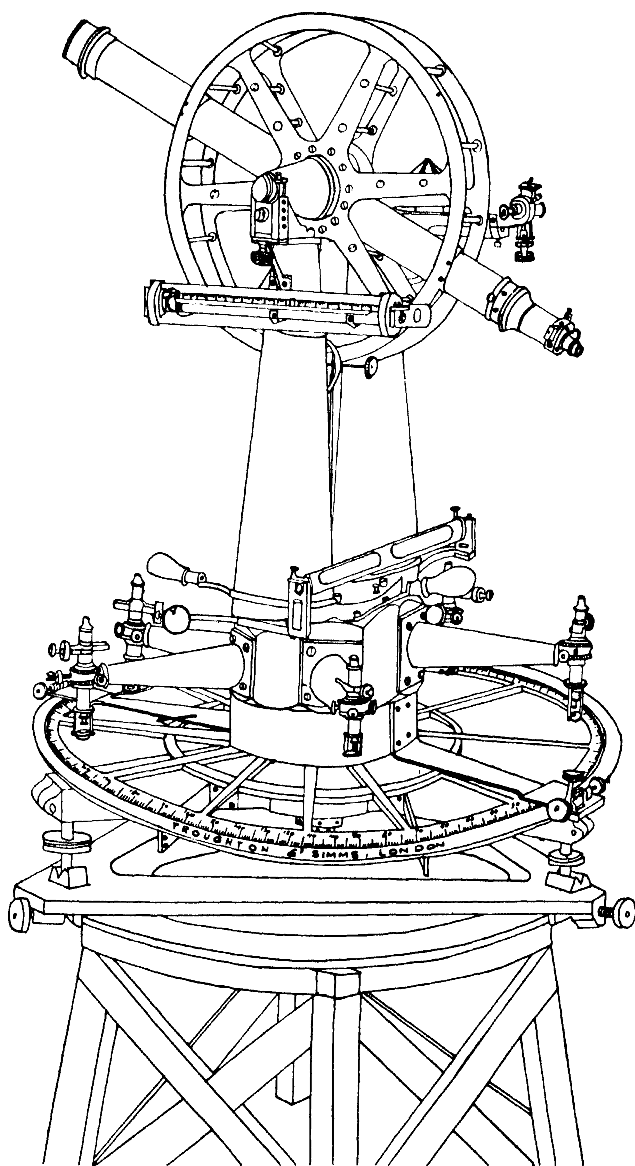


FIG. 10.3. Sketch of the Theodolite, assembled by S. Mohsin Husain and used by Waugh and his associates, now preserved in the Victoria Memorial Museum, Calcutta. (Courtesy, Sri S. N. Sen who got the sketch made in connection with the *Inventory of Scientific Instruments of Historical Importance*, now under preparation by him.)

During Waugh's time, attention was also paid to the formation of a gridiron of triangulation to the westward of the Great Arc series in the Panjab and Sind. This work which was commenced in 1847 was nearing completion when Waugh retired in 1861. About this time (1855), the work on the Kashmir series was also in progress under the direction of Captain Montgomerie. On the retirement of Waugh, the government bifurcated the offices of the Superintendent of the Great Trigonometrical Survey and the Suveryor-General, and appointed Colonel Walker to the first, and Colonel Thuillier to the second. Walker continued the work on the Great North-Western Gridiron and remeasured some of the Great Arc series.

Radhanath Sikdar

The notable Indian who did remarkable work in the Great Trigonometrical Survey of India was one by name Radhanath Sikdar (1813–1870). A distinguished student of the Hindu College (Calcutta), Radhanath joined the Trigonometrical Survey in 1831 and made a name for himself in the survey work and the associated mathematical applications. He accompanied Everest, Waugh and Renny in their work concerning the Great Arc, and was found to be the ablest of the eight of the native computers then working. He proved his acumen by preparing the *Auxi Tables.* George Everest said of him thus: '. . . a hardy, energetic young man who received an exceedingly good education in mathematics at the Hindoo College . . . Of the qualifications of Radhanath I cannot speak too highly; in his mathematical attainments there are few in India—European or native—that can at all compete with him; and it is my impression that even in Europe these attainments would rank very high. As a computer he is quite indefatigable and there is no person in my department so thoroughly skilful in the application of the various formulae . . . Eventually he will furnish a convincing proof that the aptitude of your countrymen for the practical, as well as the theoretical parts of mathematics, is no wise inferior to that of Europeans.'[a] In 1864, Radhanath was elected a Corresponding Member of the Society of Natural History (Bavaria)—a rare distinction conferred by a reputed German Philosophical Society on a foreigner. He was for several years on the Physical Science Committee of the Asiatic Society, and compiled the meteorological observations (1853–1864) which appeared in the Society's *Journal.*

BOTANICAL INVESTIGATIONS

Roxburgh

In the nineteenth century, the botanical investigations took rapid strides and the efforts made earlier towards cultivation of the commercially important exotic plants met with considerable success. Roxburgh set an

[a] Phillimore, IV, pp. 340–41; 461.

example for those who collaborated with or followed him by his zeal and devotion to the study of plants as well as cataloguing them scientifically. The Indian Linnaeus, as Roxburgh became known later, systematically formulated and gave a scientific shape to the Garden. Under his care and influence, the Garden, in addition to its being a viable ground for promoting plants of commercial interest, became an active centre of botanical investigations. In this respect, he appeared to have drawn inspiration from the earlier work of Koenig. Roxburgh drew up a catalogue of about 3,500 species growing in the Garden, and employing local artists, prepared illustrations of a number of plants. His work was published in two parts in 1814 under the name *Hortus Bengalensis* by his trusted friend William Carey (1761–1834), who himself had developed an admirable Botanical Garden at Serampore near Calcutta. Roxburgh also compiled vast information for his important publications, viz. *Flora Indica* (excluding that of the Himalayas; published posthumously in 3 vols; 1820, 1824 and 1832 under Carey's editing) and *Plantae Coromandelianae* (in 3 vols; 1795, 1802 and 1819). His labour did not end with them. He produced over 2,300 coloured illustrations in 35 volumes depicting various plants. In fact these illustrations were found very useful by the famous botanist of the Kew Garden, Joseph Dalton Hooker (1817–1911), when he planned his *Flora of British India.* For his systematic and untiring botanical work, Roxburgh has been rightly reckoned as the 'Father of Indian Botany'. In the words of George King who worked about fifty years later at the Garden: 'Roxburgh was the first botanist who attempted to draw up a systematic account of the plants of India and his book, which is on the Linnaean System, is the basis of all subsequent works on Indian botany, and until the publication of Sir Joseph Hooker's monumental work, it remained the only single book through which a knowledge of Indian plants could be acquired.'[a] Roxburgh was succeeded by Buchanan Hamilton (1762–1829) who was a zoologist as well as a botanist. He had already explored the Mysore and Bengal areas and produced a commentary on van Rheede's *Hortus Malabaricus.* He sent about 1,500 specimens and 400 drawings to his friends in Europe.

Nathaniel Wallich and William Carey

The Dane Nathaniel Wallich (1786–1854), who was Professor at the Medical College, Calcutta, succeeded Buchanan Hamilton in 1815 as the Superintendent of the Botanic Garden. He came to India as a surgeon in the Danish settlement of Serampore. That was the time when Britain and Denmark were at war as a consequence of which, in India, Serampore was annexed by the Britishers, and Wallich was among the prisoners held by them. However, the East India Company did not lose much time in making use of his acumen and permitting him to undertake botanical exploration. Wallich, too, displayed great enthusiasm, undaunted by the

[a] Santapau, p. 3.

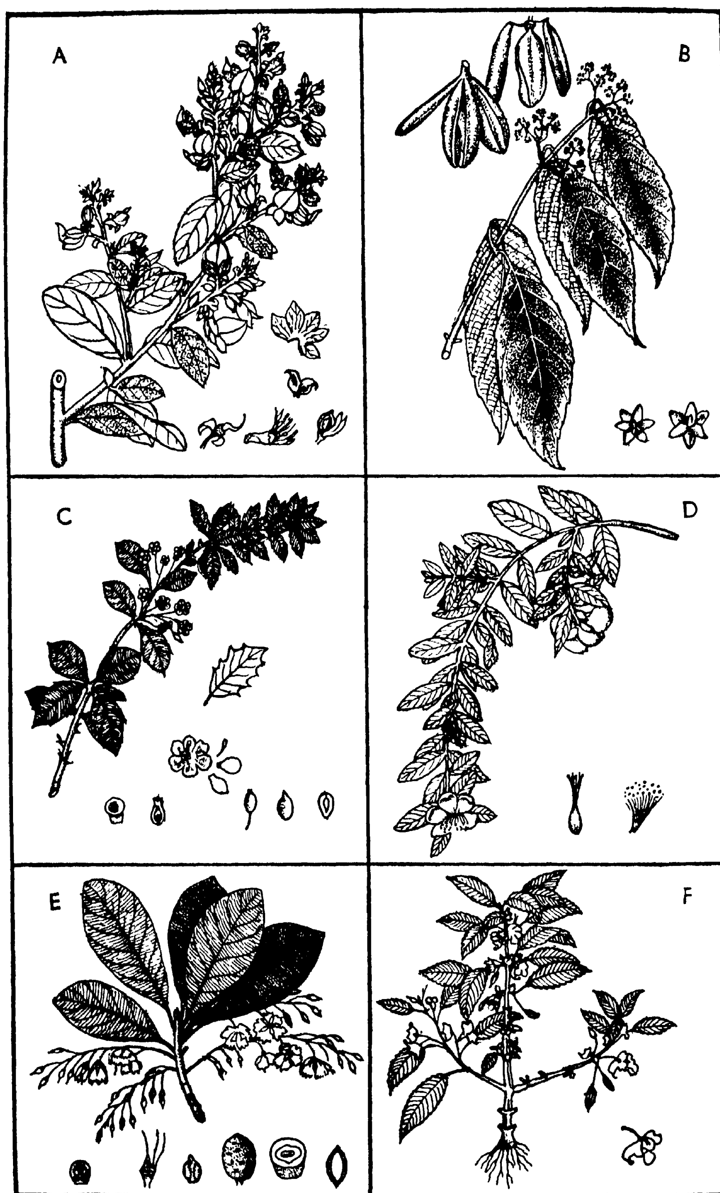


FIG. 10.4. Sketches of six botanical specimens. (Reproduced from the coloured illustrations of *Icones Roxburghianae.*) (A) *Crotalaria fulva* Roxb. (*Fasc.* IV, p. 14); (B) *Hippocratea arborea* Roxb. (*Fasc.* III, p. 46); (C) *Berberis asiatica* Roxb. (*Fasc.* I, p. 16); (D) *Hypericum cernuum* Roxb. (*Fasc.* I, p. 28); (E) *Elaeocarpus ganitrus* Roxb. (*Fasc.* II, p. 38); (F) *Impatiens* [illegible]

new situation, and proceeded with botanical investigations in Nepal, Assam, Penang, Singapore, etc., and classified his rich collections. Later he donated the major part of his collection to the Linnaean Society (founded

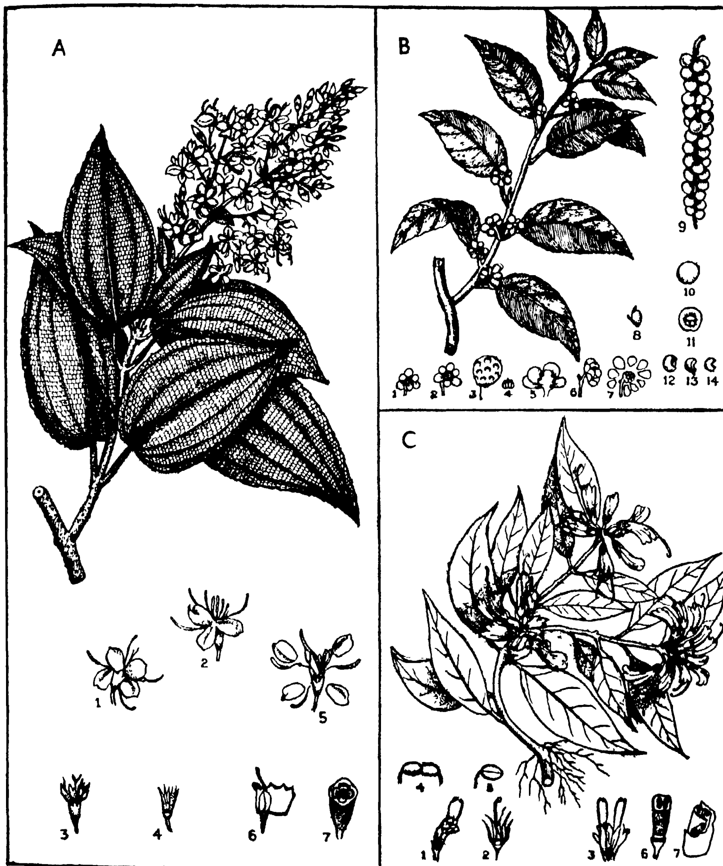


FIG. 10.5. (A) *Oxyspora paniculata* Wall. (Reproduced from Wallich (2), p. 88.)
(B) *Kadsura propinqua* Wall. (Reproduced from Wallich (1), Tab. 15.)
(C) *Aeschynanthus ramosissima* Wall. (Reproduced from Wallich (2), p. 71.)

in England in 1720). The European botanists of his time looked upon these collections as a veritable mine of information for their own researches. Wallich is remembered for his work, *Plantae Asiaticae Rariores* (3 volumes; 300 coloured plates; published in 1832 by the East India Company) and *Tentamen Florae Nepalensis*. He collaborated with William Carey in the later publications of Roxburgh.

William Carey, as already mentioned, took a leading part in the founding in 1820 of the Agricultural Society of India. Carey was a remarkable investigator and, as noted already, had developed a botanic garden including a herbarium on his own at Serampore, and spared no efforts for the successful propagation of certain imported seeds and plants on the Indian soil. After Carey's death, his herbarium was donated to the University of Copenhagen, and the duplicates to William Hooker in England. In 1842 Voigt, his disciple, brought out a united catalogue of the plants grown in the Botanic Gardens at Serampore and Sibpur under the title *Hortus Suburbanus Calcuttensis.*

Other Investigators

In the south, Robert Wight (1796–1872), who was working at Samulcottah, went about in a systematic manner and collected a number of plant specimens, some of which were sent to Robert Graham at Edinburgh and William Hooker at Glasgow. He brought out jointly with Walter Arnott the publication entitled *Prodromus Florae Peninsulae Indiae Orientalis* (1834). Griffith was another collector who gathered as many as 9,000 species in the thirteen years of his stay in India at this time.

Complementary to the Botanic Garden at Calcutta was one at Saharanpur. George Govan, John Forbes Royle and Thomson worked there, and threw light on the botany and other branches of the natural history of the Himalayan mountains. Hugh Falconer who was at this garden and later at Calcutta brought to light the fossil flora of India.

Thomas Thomson conducted botanical investigations in the northern plains, the Himalayas as well as Kashmir. He collaborated with John Dalton Hooker (son of William Hooker) in the publication of the first volume of *Flora Indica* (1855). Their combined collections were astonishingly of the order of 150,000 specimens (about 9,500 species). Thomas Anderson (1832–1872) succeeded Thomas Thomson at the Botanic Garden. Charles Baron Clarke (1832–1908), who was also associated with the Garden, though a mathematician by training, took great interest in the flora of India and tried to categorize them 'areawise' (phytogeographically). He is well known for his monograph on the ferns of northern India.

The Herbarium

The Garden with its 15,000 trees and shrubs including a 200-year-old great banyan tree (about 950 roots; circumference 1328 ft.) and a number of astounding herbaceous species is a living storehouse of botanical knowledge. Its Herbarium is a house of almost all the dried plant materials of the whole of the Indian subcontinent, Asia, Europe and Australia. Nathaniel Wallich, as stated before, distributed its rich botanical collections to the principal institutions and botanists of Europe. The present collections date from 1832. George King says in the Centenary Report of the Botanic Garden: '...It (the Herbarium) consists of plants contributed by

almost every worker of botany in India since that date, and of considerable contribution from botanists in Europe. It is first and foremost an Indian Herbarium, but the plants of South-Eastern Asia, of Japan, of Persia and of Asia Minor are fairly well represented. Those of Europe are also excellently represented; but in African and American plants the collection is comparatively poor. Constant communication and interchange of specimens have been kept up for the last fifty years with the great nation collection at Kew, and to the distinguished Directors of that institution, Sir William Hooker and his son and successor Sir Joseph, the Calcutta Herbarium is indebted for valuable contributions. Interchanges have also been kept up with other European botanic institutions, such as the Herbarium of the British Museum, of the Jardin des Plants, Paris, the Imperial Gardens at St. Petersburgh and Berlin, the Royal Botanical Gardens at Buitenzorg in Java, at Peradeniya in Ceylon, and at Saharanpur; and many other institutions.' The Herbarium, the first in India and recognized as one of the most important herbaria in Asia, has indeed vast collections numbering over two millions of specimens. Housed earlier in the Superintendent's bungalow, they are now meticulously preserved in the building which became available in 1883 and 1884.

George King

The Garden suffered extensive damage from two terrible cyclones which occurred in 1864 and 1867. As a result of the cyclone of 1864, it was submerged in six to seven feet deep water, and the saline tidal effect produced a distressing spectacle. In 1871, the Garden was renovated and reorganized under the direction of its new and energetic Superintendent George King, who also worked out its phytographical arrangement.

Qualified in medicine in the University of Aberdeen, King came to India as Superintendent at the Saharanpur Garden (1869), was Assistant Forest Conservator at Dehra Dun (1869–1870) and a year later was transferred to Calcutta to work at the Botanic Garden. He was also appointed as Professor of Botany at the Medical College, Calcutta. The present Botanical Survey of India was established in 1890 mainly as a result of the persuasive efforts of King who became the first *ex-officio* Director of the Survey. He collected valuable materials relating to the flora of the Malay Peninsula. In 1887 he started the publication of the *Annals of the Royal Botanic Garden*. His meritorious service resulted in his becoming later the Director of the Royal Botanic Garden at Kew (1897).

David Prain

After the retirement of George King, David Prain who was then the Curator of the Herbarium became the Director of the Botanical Survey. He undertook a number of taxonomic studies relating to Papaveraceae, Leguminosae, Scrophulariaceae and the like, and brought out a series under

the title *Noviciae Indica* (1889–1898). Later he published a book under the title *Bengal Plants.*

The Botanical Survey of India

The object of the Botanical Survey of India was not only to intensify the botanical exploration of the country particularly of the western Himalayan region but also to co-ordinate the scientific activities of the provincial botanical departments in Bombay, North-West Frontier Provinces, Madras and Bengal. Theodore Cooke, who was then the Principal of Science College, Poona, was the Director for Bombay region, J. F. Duthie was for north-western India at Saharanpur, and M. A. Lawson was for the southern region at Madras. They had undertaken a number of important botanical investigations. As a result, valuable publications like *Flora of the Bombay Presidency* (Theodore Cooke, 2 vols; 1901–1908), *Bengal Plants* (Prain 1903) and *Flora of Upper Gangetic Plain* (Duthie) were brought out, while the *Flora of Madras* appeared later. The scientific investigations of the Botanical Survey of India have been largely responsible for the growth in the Indian soil of several exotic plants of commercial importance such as cinchona, rubber, tea, potatoes, coffee, certain fibrous plants, spices, and tobacco.

GEOLOGICAL EXPLORATIONS

EARLY INVESTIGATIONS

In the early decades of the nineteenth century, some of the versatile European naturalists, medical men and engineers were, in addition to their own fields of employment, actively engaged in geological investigations in the Deccan, central and north India, and the Himalayas. In 1820 H. W. Voysey, who as a surgeon was associated with the work of Lambton in the latter's survey work, published an account of the diamond mines of south India.[a] He also prepared a geological sketch of the 'Nalla Mala Mountains', north of the river Krishna, and suggested the name of 'Clay Slate Formation' to the rocks of which the mountains are composed. In 1835 P. M. Benza, who was surgeon to the Governor of Madras, examined the geology of the Nilgiris and noticed the basaltic dykes. He described specially the several varieties of iron ores occurring in the region, as also the highly fossiliferous intertrappean limestone with oyster and other shales at Rajamundry.[b] Another medical man, T. G. Malcalmson, studied the formation of the Deccan Trap, and also gave an account of the Lonar Lake as being in the form of a 'vast crater nearly 500 feet deep, and four or five miles round on the upper margin, the water being green and bitter, supersaturated with alkaline carbonate, and containing *silex* in solution, as well as some iron'.[c] Captain J. T. Newbold studied systematically the geology of southern

[a] Voysey, p. 120. [b] Bose (P. N.) (1), pp. 29–30. [c] Malcalmson (2), p. 302.

India, particularly between Bellary and Bijapur between the years 1836 and 1847. He observed the chloritic band as well as the clay iron beds at some places, and threw light on the origin and age of *kankar*, *regur* and laterite. It was Newbold who first detected the occurrence of veins of manganese in the laterite. His classification of the rocks of the south Maharashtra region is well known.[a]

In central India, Captain James Franklin sought to describe the formation of the Vindhyan. In 1833 R. Everest examined the sandstone and trap formation in the west of Mirzapur,[b] while J. Finnis investigated the lithology of the rocks found between Nagpur and Hoshangabad in 1834.[c] During 1848–1852 Captain W. S. Sherwill of the Revenue Survey was the first to examine the structure of the Rajmahal hills.[d] He also discovered the coal of the Chuparbhita Pass. About this time, J. Homfrey's first published account on the Raniganj coalfields as contained in his descriptions of the Damodar Valley also appeared.[e]

As to the geology of the Himalayas, Captain J. D. Herbert's is a judicious and scientific account which describes the rocks and other formations of the mountains as well as the minerals found in the region.[f] In 1831 H. Falconer explored the Siwalik hills and inferred the Tertiary Age of this formation, comparing it with the Molasse Horizon of Switzerland.

PALAEONTOLOGY

The most outstanding work of Falconer was on the fossil bones of the Siwalik region, in association with Proby Cautley (the foremost engineer at that time in charge of the Jamuna Canal Project), which has earned for the former a great name as a palaeontologist. Falconer, Cautley and two other engineers, William Baker and Henry Durand, brought to light the remarkable fossil fauna of the Sub-Himalayan Range.[g, h] The sketches in Fig. 10.6 represent the four fossils of *Mastodon perimensis* Falc. and Caut., *Sivatherium giganteum* Falc. and Caut., *Mastodon sivalensis* Falc. and Caut. and *Equus sivalensis* Falc. and Caut., discovered by Falconer and Cautley in the Siwalik hills, the originals of which have been preserved in the British Museum of Natural History and reproduced from the cast collections of the Geological Survey of India, preserved in the Indian Museum, Calcutta. 'Unequalled for richness and extent in any other region then known, the fossils created no little sensation throughout the scientific world. The Wollaston Medal in duplicate was awarded in 1837 to both Falconer and Cautley by the Geological Society of London; and the learned societies of Europe and America hastened to mark their appreciation by the bestowal of appropriate honours. Sir Charles Lyell announced the award of the

[a] Newbold, p. 268.
[b] Everest (1), p. 475.
[c] Finnis, p. 71.
[d] Sherwill, p. 3.
[e] Homfrey, p. 728.
[f] Herbert, pp. i–clxiii.
[g] Falconer, pp. 233–34.
[h] Falconer and Cautley (1), p. 706; (2), pp. 38–50; (5), pp. 39–53; (4), pp. 115–34; (5), 193–200; and (6), p. 193.

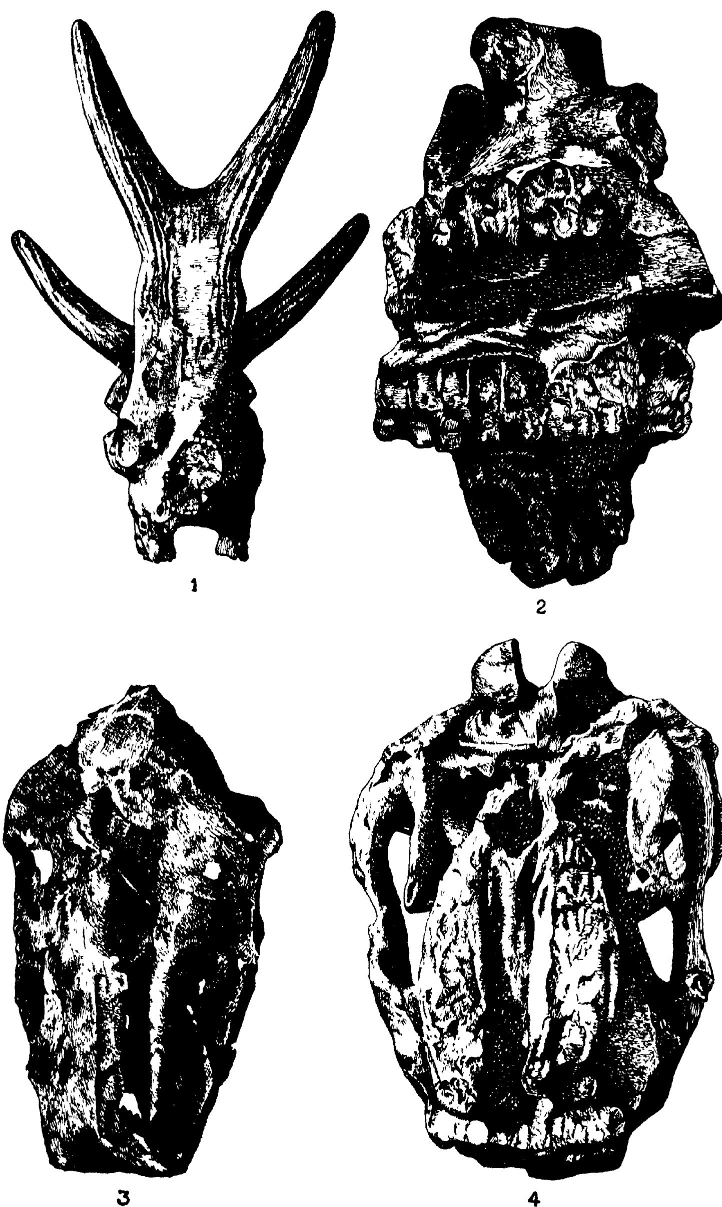


FIG. 10.6. Sketches of four fossils discovered in the Siwalik hills by H. Falconer and P. Cautley. (Originals preserved in the British Museum of Natural History; reproduced from the cast collections of the Geological Survey of India preserved in the Indian Museum, Calcutta.) (1) Cranium of *Mastodon perimensis* Falc. and Caut.; (2) cranium of *Sivatherium giganteum* Falc. and Caut.; (3) palate and part of cranium showing 2nd and 3rd molars of *Mastodon sivalensis* Falc. and Caut.; (4) cranium of *Equus sivalensis* Falc. and Caut.

Geological Society of London in terms which must have been no mean incentive to young Falconer for he was at that time under thirty.'[a] The Memoirs by Falconer and Cautley on the *Sivatherium giganteum*, *Felix cristata* and *Ursa sivalensis*, and on fossil species of the camel and hippopotamus were published in the *Asiatic Researches*. Apart from these, Falconer completed in 1855 a descriptive catalogue of the vertebrate fossils of the Siwalik hills, the Narmada, Perim Island, etc., which were preserved in the Museum of the Asiatic Society. When he died, a committee consisting of the presidents of the Royal, Linnaean, Geological, Geographical, and Ethnological Societies of England raised a 'Falconer Memorial Fund', and installed his marble bust in the Royal Society. Falconer's *Fauna Antiqua Sivalensis* was edited and published by Murchison in 1865 posthumously.

Of the other early important geological investigations, special mention may be made of the work done by A. Fleming of the Bengal Medical Service on the Salt Range of the Panjab during 1848–1853. He described the height and course of the Salt Range as also its physical features and stratigraphy.[b] Another investigation was by Captain Hannay who studied meticulously the earthquakes in Assam for about four years (1839–1843),[c] Colonel Baird Smith of the Bengal Engineers also recorded and analysed the nature of Indian earthquakes, and even made observations on the general distribution of subterranean disturbing forces in operation throughout India. In 1845 he published a comprehensive account of the Asiatic earthquakes which occurred in 1843.[d] Apart from these investigations, I. A. Hodgson and R. Everest studied glacial and river actions respectively.

GEOLOGICAL SURVEY OF INDIA

In 1835 the government became interested in making adequate supplies of coal for the steamers for purposes of navigation. In the very next year Governor-General Auckland constituted a committee for the investigations of coal and mineral resources of India, with John McClelland of the Medical Services as its Secretary. The committee enjoined on the government that immediate steps be taken for a 'geological survey of the coal formation in India'.

The economic value of the geological investigations proved of immediate concern to the East India Company, the coalfields of the eastern parts of India looming large in this respect. Then in Britain, geology more than chemistry had assumed importance as a very useful branch of science with far-reaching practical possibilities. The result was that in 1835 the Geological Survey of Great Britain was formed. The British Association for the Advancement of Science (founded in 1831) came forward prudently enough to offer financial support to geological investigations. In this direction again the Indian coalfields and other mines looked very

[a] Bose (P. N.) (1), p. 61.
[b] Fleming, pp. 229–79, 333–68, 444–62.
[c] Hannay, p. 907.
[d] Smith (R. B.), p. 604.

attractive. On the initiative of McClelland, D. H. Williams of the British Geological Survey came to India in 1846, and his immediate concern was with the exploration of the coalfields in Raniganj, Jharia, Taldange, Dhanbad and Karanpura areas. He set about it in a planned way and in less than two years was able to survey a number of coalfields. It was the desire of Williams to conduct the investigations up the Damodar valley. However, towards the end of 1848 he got an attack of jungle fever and died in Hazaribag. Truly Williams laid the foundation for the geological survey of India.

In 1851 Thomas Oldham succeeded Williams as Superintendent of the Geological Survey of India. He was only 35 years of age then and already a Fellow of the Royal Society of London, Professor of Geology in the University of Dublin, Local Director of the Geological Survey of Ireland, and President of the Geological Society, Dublin.[a] With his coming to India, the geological investigations became broadbased and more purposeful as he undertook in an effective manner a systematic geological survey of India. In this task Oldham received great encouragement from Governor-General Canning who evinced abiding interest in the geological explorations. As a consequence, officially, the Geological Survey of India was established as a Government Department. The object of the new organization, as assented to by the Governor-General, was to have 'coalfields of this country systematically surveyed'. As a result, in the next two decades the Survey's activities were in the main confined to protracted investigations of coalfields in Jharia, Bokaro, Narmada valleys, etc.

The Geological Survey of India made rapid progress and had to its credit a number of achievements in the later half of the nineteenth century, under the successive directions of Thomas Oldham, H. B. Medlicott, William King and C. L. Griesbach. A concise and authentic account of the steps taken by Oldham to place the new organization on a solid foundation, and also the varied investigations of the Survey have been given in the publication issued in 1951 on the occasion of the centenary of the Survey. While the reader is referred to this publication, as also the papers, reports and notes which appeared particularly in the *Memoirs* and *Records* of the Geological Survey of India, the following briefly highlights some of the important geologists and their main investigations up to the end of the nineteenth century.

Thomas Oldham

Oldham was indeed a meticulous and imaginative investigator, who brought to bear upon his investigations a rare insight nurtured by deep experience, the impact of which was felt by his co-workers as well as those who followed him. Among his co-officers were J. G. Medlicott, W. Theobald, H. B. Medlicott, W. T. Blanford and H. F. Blanford. His early works in India related to the examination of the Khasi hills, Damodar valley, Rajmahal

[a] Markham, pp. 216–17.

hills, the entire coal-producing context of the Bengal region and the coal belts of the Satpura range.

He proposed the name *Vindhyan*[a] to connote the great Sandstone Formation of the northern and central India, and indicated that the Vindhyan, noted as it is for the absence of organic remains, could not well be correlated with any of the great European formations. This led him to believe that it might be Cambrian. He was able to establish the identity of the vast thick layers of sandstones and shales with plant fossils which lay on the Vindhyan, with the coal groups of Burdwan, Hazaribag and Cuttack. He gave the name *Mahadevas*[b] to the series of thick and ferruginous sandstones. With great ingenuity he classified different rock groups[c] and was hopeful of finding an accurate parallelism between the rocks of India and those of Australia.

Oldham also initiated the study of the earthquakes in India.[d] Under his able guidance, the first catalogue of the Indian earthquakes as also a list of some 300 thermal springs[e] in India were compiled. Further, it was Oldham who realized the necessity and importance of training some Indians as geologists through apprenticeship. He followed it up by recruiting Ram Singh (1873), Kishen Singh and Hira Lal (1874).

H. B. Medlicott

H. B. Medlicott, who was Professor of Natural History and Economic Geology at the Thomson College of Engineering at Roorkee,[f] joined the Geological Survey in 1854, and worked with Oldham. He studied the Himalayan geology from 1857 to 1861. He also threw light on the glacial action relating to the great blocks of gneissose granite along the base of the Dhuladhar in the Kangra valley.[g] His survey of the northern side of the Narmada valley enabled him to confirm the threefold division of Vindhyans. He showed that the rocks of the Raipur basin did not belong to the coal-bearing series. It was Medlicott who suggested the term *Gondwana*[h] for the great southern continent. In 1876 Medlicott succeeded Oldham as Superintendent, and was designated as Director of the Geological Survey of India in 1885.

W. T. Blanford and others

W. T. Blanford, who joined the Geological Survey in 1885, was a geologist of distinction. He surveyed the Raniganj coalfield (1858–1860), and recognized three different groups of rocks there.[i] He prepared a geological map detailed on the scale 1″ : 1 mile which was first to be published on that scale. Further, he examined the physical geography of the

[a] Oldham (1), p. 304.
[b] Oldham (1), p. 315.
[c] Oldham (1), pp. 300–26.
[d] Oldham (3), pp. 163–216.
[e] Oldham (2), pp. 99–162.
[f] Markham, p. 225.
[g] Medlicott (2), p. 64.
[h] *Centenary of the GSI*, p. 9.
[i] Blanford (W. T.) (1), pp. 1–196.

great Indian desert,[a] and surveyed also the eastern and northern frontiers of Sikkim. Both Oldham and Blanford worked on the correlation and classification of the peninsular formation of India. Blanford and his brother, H. F. Blanford, along with W. Theobald examined the Talchir boulder-beds in the Cuttack district and ascribed their origin to ice action. For his distinguished work, Blanford was awarded the famous Wollaston Gold Medal by the Geological Society of London.[b] Another noted geologist was O. Feistmantel who studied the plant fossils and attempted to classify the Gondwana System based on them.

In the south, H. F. Blanford examined the geology of the Nilgiri hills.[c] F. Stoliczka, who was another geologist working in the south, brought out in four volumes the Cretaceous fauna of southern India. Bruce Foot investigated the southern regions of Trichinopoly as well as Bellary areas. V. Ball was another noted geologist of the Survey, who made distinct contributions to the understanding of the geology of the Andaman and Nicobar Islands. The rocks of the Nicobar were shown by him to be coral, magnesium claystone with conglomerates, gabbro and serpentine in confirmation of the earlier observations of Hochstetter.[d]

William King (who succeeded H. B. Medlicott in 1887 as Director of the Geological Survey of India) discovered the Singareni coalfields in the State of Hyderabad. In 1872 T. H. Holland discovered large deposits of high-grade iron ore, chromite and magnesite in the Salem district of Madras, and corundum in Mysore. In 1893 he came across an acidic pyroxene-bearing (hypersthene) rock in the Madras Province, and to this he proposed the name *Charnockite* in memory of Job Charnock, the founder of Calcutta.[e]

'Among the results which have influenced the course of geological science may be placed the recognition of the importance of deposits formed in land, the great Vindhyan and Gondwana System and the Gangetic alluvium being revealed as land deposits. The recognition of the Upper carboniferous glacial epoch in India, extending into Australia, South Africa and South America, gave rise to the conception of the vast southern continent of Gondwanaland. The study of the Assam earthquake, in 1897, led to the discovery of three main types of earthquake waves—a discovery that has proved so fruitful in investigations regarding the internal structure of the earth. The rich fossil mammalian fauna of the Siwalik hills, described in a series of brilliant *Memoirs* which adorn the museums of the world, throw light on the evolution of the mammals and even of man himself.'[f]

Pramatha Nath Bose

In 1851 when the Geological Survey of India formed its nucleus, there were only one superintendent and two assistants, and in 1861 the number

[a] Blanford (W. T.) (2), p. 86.
[b] Bose (P. N.) (1), p. 40.
[c] Blanford (H. F.), p. 241.
[d] Bose (P. N.) (1), p. 46.
[e] Holland, pp. 117–249.
[f] *Centenary of the GSI*, p. 116.

of officers rose to 12. However, it was not before 1873 that the Indian apprentices were able to join the Survey and participate in the geological investigations, even as subordinate assistants. The honour of being the first Indian to hold a graded position in the Geological Survey of India belonged to P. N. Bose (1880). P. N. Dutta was another who joined the organization in 1888. By the end of the century there were fourteen officers in the Geological Survey out of whom only two were Indians. Both P. N. Bose and Dutta were geologists of high distinction. The former mapped the Vindhyans and the igneous rocks of Raipur and Balaghat areas of the Central Provinces. P. N. Bose was the first to give accounts of microsections of rocks in the progress reports. P. N. Dutta discovered the vast deposits of manganese ore in the Bandara and Chhindwara river valley (1893–1894), besides the Devonian and Mesozoic beds of the northern Shan States.



FIG. 10.7. Sketches showing microsections of igneous rocks from Raipur and Balaghat districts, Central Provinces. (Reproduced from Bose (P. N.) (2), p. 61.)

P. N. Bose retired from the Geological Survey in 1903 when T. H. Holland (who joined the organization eight years later than he) succeeded him as Director. Bose's geological acumen attracted the attention of the Maharaja of Mayurbhanj and, as a result, he became the State Geologist of Mayurbhanj. It was largely due to his efforts that the extensive as well as rich deposits of iron ore in that State were discovered. Later, there came about an accidental meeting between Bose and the renowned industrialist J. N. Tata who, on the advice of the former, soon took active steps for establishing an iron and steel works at the present location at Jamshedpur.

Apart from the geological investigations with which the Geological Survey was primarily concerned, it had realized the importance of imparting education in geology at collegiate level. As early as 1892, it moved in this matter and even permitted one of its officers to work as part-time Professor

of Geology at the Presidency College, Calcutta. T. H. Holland was the first professor of this type. The Geological Survey also began to recruit several specialists in mining and metallurgy towards the close of the nineteenth century, during the time of C. L. Grieshback, and these specialists constituted the nucleus of staff of the Department of Mines and Inspection which, first organized in 1902, was later designated as the Department of Mines.[a]

THE INDIAN MUSEUM

The scientific investigations conducted by the members of the Asiatic Society in different parts of the country and on different branches of natural history necessarily led to the accumulation of a wide variety of materials and curios such as the ancient relics, coins, plant specimens and minerals. Though the Society did not conceive of the establishment of a museum, gradually it was realized that the accumulated objects deserved preservation. As early as 1796, the idea gained ground that a suitable house be built for their reception, preservation and presentation. But the Asiatic Society itself had to wait till 1808 to move into a house of its own. In 1814 Nathaniel Wallich entered a powerful plea for the establishment of a museum to house 'the object of science and of those reliques which illustrate ancient times and manners'. To quote from his note submitted to the Asiatic Society for this purpose: 'It is, however, in the department of science that a museum in this country would be found most specially serviceable and the facility of the accumulation is proportionable to the extent of its utility. In natural history, botany, anatomy, chemistry, mineralogy, and other branches, a collection would accumulate rapidly if once commenced; and from the first moment of the accumulation would furnish additional matter into the stock of knowledge.'[b] And in 1814 the Asiatic Society resolved that a museum be formed 'for the reception of all articles that may tend to illustrate oriental manners and history, or to elucidate the peculiarities of art and nature in the East'. The last included the native manufactures, animal skeletons, birds (stuffed or preserved), dried plants and fruits, minerals of every description, metals and alloys. Wallich was rightly chosen as the Honorary Superintendent of the 'Oriental Museum of the Asiatic Society'. The museum was broadly divided into two sections: (i) archaeological, ethnological and technical; and (ii) geological and zoological. The collections of Wallich, Colonel Stuart, Tytler, General Mackenzie, Brian Hodgson, Captain Dillon and Babu Ram Kamal Sen were among the first curious objects of the museum. After the resignation of Wallich, curators were appointed from time to time on payment of small amounts for longer or shorter periods.

In 1835 the Government of India, encouraged by the working of coal mines and the discovery of new minerals, conceived the idea of founding a

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[a] Ghosh (A. K.) (1), pp. 331–33; (3), pp. 307–10.

[b] Mitra, p. 33.

Museum of Economic Geology at Calcutta,[a, b] and provided necessary financial assistance to the Asiatic Society to preserve the government's collection. In 1836, however, when the finances of the Asiatic Society were crippled as a result of the failure of its Bankers, attempts were made to get a grant from the government with a view to employing a paid whole-time curator on a modest monthly salary to look after the 'public depositary of the products of nature in India' under the care of the Society. But it was not till 1839 that the Court of Directors in London could sanction the grant for the salary of the curator, maintenance of the museum and for certain other purposes. In the meantime the Society persisted in its demand and presented a second petition for securing a temporary grant, which met with the approval of the government. J. T. Pearson of the Bengal Medical Service was appointed Curator who was succeeded by McClelland, the distinguished ichthyologist. In 1841 Edward Blyth who was chosen by H. H. Wilson in England became the paid whole-time Curator.

As noted above, the Society with the financial support of the government had also preserved the government's collection of minerals, fossils and the like under the name of Museum of Economic Geology. In May 1841 Captain G. D. Tremenheere, who was sent by the government to England to procure more such collections, returned with a large treasure of specimens of minerals which needed preservation and proper arrangement. But as Blyth was not by training a geologist, the necessity arose for employing yet another curator for the management of the geological collections for which purpose Piddington was appointed. The Curators Blyth and Piddington steadily built up the collections, classified the exhibits and brought to light the scientific knowledge latent in them. In 1856 the collections owned by the Government were removed and displayed at in the office of the Geological Survey of India. In the meantime, the archaeological and zoological collections continued to pour into the Asiatic Society building.

Time was now ripe for the foundation of a well-planned museum in Calcutta.[c] The Asiatic Society took the initiative between the years 1856 and 1858, and negotiated with the government for the transfer of its own collections to such a public museum under certain terms. In 1867 came into being the Indian Museum under the Act No. XVII of 1866 passed by the Governor-General of India in March 1866. The Act envisaged: 'The Governor-General of India in Council shall cause to be created, at the expense of the Government of India, a suitable building in Calcutta or near the site now occupied by the Small Cause Court, to be devoted in part to collections illustrative of the Indian archaeology and of the several branches of the Natural History, in part to the preservation and exhibition of other objects of interest, whether historical or economical, in part to the records of the offices of the Geological Survey of India, and in part to the fit accommodation of the Asiatic Society of Bengal.' The names of Trustees

[a] Markham, p. 233. [b] Piddington, pp. 322–40. [c] *Indian Museum: 1814–1914*, pp. 5–9.

of the Museum were also proposed, with Barnes Peacock, the then Chief Justice of Bengal, as the President.

John Anderson, who had served earlier as Professor of Natural Science in Free Church College at Edinburgh, became the first Curator[a] of the new Museum in September 1866. In recognition of his knowledge, Anderson was also permitted by the Board of Trustees to hold the professorship of anatomy at the Medical College, Calcutta, in addition to his duties at the Museum. James Wood-Mason, who assisted Anderson in organizing the Museum for about 16 years, succeeded the latter as Superintendent of the Museum in 1886.

The Asiatic Society made over its rich collections of zoological, geological and archaeological objects to the Board of Trustees of the Museum. Later the Society was paid 1½ lac of rupees as compensation for its claim to accommodation in the projected building for the Museum. The building itself became ready for occupation in 1875. On the first of April 1878, the galleries were thrown open to the public. Immediately after the Great Exhibition which was held at Calcutta in 1883, the industrial collections displayed at the exhibition had to be amalgamated into the Indian Museum. The new display sector needed additional accommodation and in 1891 a new wing in Sudder Street came up for this purpose.

The Indian Museum, based on the pattern of British Museum, is indeed an interesting and valuable assemblage of the scientific and the artistic sections. The public galleries are divided into (i) archaeological, (ii) geological, (iii) industrial, (iv) zoological, (v) anthropological (ethnological) and (vi) art sections. The last is the only section in charge of the Trustees of the Museum while the others are under the respective departments of the Government of India. The zoological and anthropological sections of the Museum gave rise to the Zoological Survey of India in 1916.

ZOOLOGICAL STUDIES

As noted already, the botanical investigations registered rapid progress in the first quarter of the nineteenth century mainly because of the devoted efforts, among others, of the two eminent botanists, William Roxburgh and Nathanial Wallich. The same, however, cannot be said of zoological researches. It would appear that no zoological study worth the name was carried out till then, and the main reason was lack of interest in zoology as such. Even such of the members of the Asiatic Society as were avowedly naturalists did not seem to be particularly concerned with zoological researches. William Jones who was so fond of natural history, strangely enough, gave expression to his disinterestedness in zoological studies in his tenth anniversary discourse to the Society, and wondered: 'Could the figure, instincts, and qualities be ascertained either on the plan of Buffon, or on that of Linnaeus without giving pain to the object of our examination?

[a] A few years later the designation was changed into Superintendent.

Few studies would afford us more solid instruction or more exquisite delight; but I never could learn by what right, nor conceive with what feeling, a naturalist can occasion the misery of an innocent bird, and leave its young, perhaps, to perish in a cold nest, because it has gay plumage, and has never been delineated, or deprive even a butterfly of its natural enjoyment, because it has the misfortune to be rare or beautiful.'[a] The compassion for the zoological objects was so strong in William Jones that he could not lend his weight to their studies.

Right at the beginning of the nineteenth century, Governor-General Wellesley took the initiative to establish a college at Fort William and attach to it a natural history department located at Barrackpore with a view to studying birds and other animals, under the leadership of Francis Buchanan. Between 1800 and 1804, many live animals arrived at Barrackpore sent by officials from different parts of the Company's territories. The institution soon languished for want of support from Wellesley's successor. In the French possession of Pondichery Jean Baptiste Leschenault de la Tour and his associates collected and examined a number of zoological specimens.[b]

Hodgson and Tickell

Early in the nineteenth century, however, Major-General Hardwicke of the Bengal Artillery and Captain Sykes of the Bombay Army made attempts to collect and describe some mammalian specimens, as also birds and insects. The first notable zoological study was in 1829 when Brian Houghton Hodgson published a paper on a new species of *Buceros*.[c] Hodgson, who was in Nepal as assistant to the Resident at Kathmandu for over twenty years from 1823, collected, with the assistance of local hunters, a large number of mammals and birds, and studied them minutely. One of the first animals studied by him was the serow named by him as *Antilope Thar*.[d] His unceasing investigations brought to light new species of *Paradoxurus* (three in number), *Cervus*, Falconidae, Merceline birds, Indian snipes, porcupines, *Plecotus*, *Talpa macruka*, a new genus of the Plantigrada, Sylviidae, Meropidae, etc.[e] The most remarkable studies of Hodgson were on the birds of Nepal and the animal named by him as Takin. His observations on the two new flying squirrels, mammals of Tibet, tame sheep and goats of the sub-Himalayas and Tibet, polecat, stag, some ruminants, monkeys, musk-deer, otter, chiru antelope and the like are characterized by 'deep research and great acumen, and are very full in details of structure'.[f] The Catalogue of his drawings and specimens of mammals and birds from Nepal and Tibet presented to the British Museum was published in 1847. It lists one hundred and fifteen species, of which about ten were from Tibet. While living in Darjeeling, between 1845 and 1858, he wrote

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[a] Bose (P. N.) (1), p. 57.
[b] Kinnear, pp. 766–67.
[c] Hodgson, pp. 178–86.
[d] Kinnear, p. 769.
[e] For details, see the relevant papers published in the volumes of *AR.*, *JASB* and *Proceedings of the Asiatic Society*.
[f] Bose (P. N.) (1), p. 58.

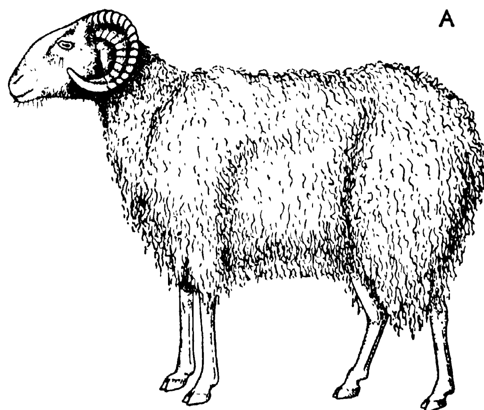


FIG. 10.8. (A) The Hooma or Blackfaced sheep of Tibet. (Reproduced from Hodgson (2), Pl. IV.)

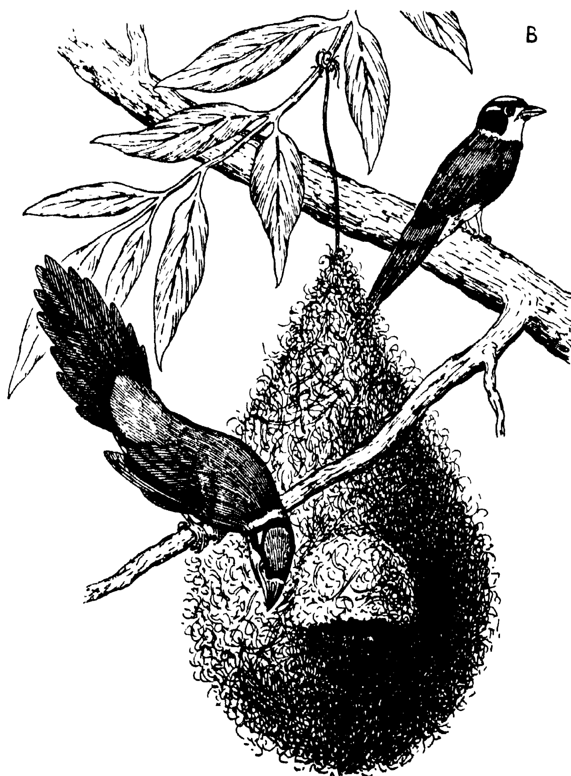


FIG. 10.8. (B) Himalayan Bradbill, *Psarisomus dalhousiae* (Hodgson's drawing). (Reproduced from Blanford (W. T.) (3), p. i.)

an important article entitled 'Physical Geography of the Himalayas' in which he described three altitudinal areas and the associated animals. Hodgson was indeed a classical worker on the Indian vertebrates.

In 1839 Walter Elliot, both an archaeologist and geologist, published a catalogue of the species of mammalia found in the southern Maharashtra country, which contains details of as many as 58 species.

Indian ornithology attained a new height as a result of the protracted studies of Lt. S. R. Tickell[a] who is regarded as one of the best field naturalists of India. For nearly 30 years he studied scientifically a number of different birds, their eggs and nests, and prepared descriptive lists of them. His observations on the birds of Borabhum and Dholbhum are of special merit.[b] He contributed to the knowledge of sloth bear, brown flying squirrel, ant-eater and the gibbons. In addition, he brought to light a new species of hornbill as well as a supposed new genus of the Gadidae of Arkan.[c] The manuscript prepared by him on the Indian mammals and birds, with adequate illustrations, is still preserved in the library of the Zoological Society of London. Blanford made use of the material of this manuscript when he wrote the *Mammals* in *The Fauna of British India* series.

Blyth

E. Blyth who, as stated before, was the first Curator of the Asiatic Society Museum worked on birds and mammals for about 22 years. His study included the specimens from India, Burma, Ceylon, Afghanisthan and the Malay Peninsula. He prepared, with characteristic zeal and care for minute details, *The Catalogues of Birds* ((1849; issued in 1852) and *Mammalia* (1863) which were in the Asiatic Society's collection. His investigations covered the species of wild sheep, predatory and sanguinvorous habits of *Magaderma*, lynx, Cuculidae, some little known birds, mole, orangutan, *Phylloscopus*, new Indian pigeon akin to the 'stock-dove' of Europe, reindeer, certain types of asses and the like.[d] In 1862 he retired to England because of ill health. It is interesting to note that Charles Darwin frequently quoted Blyth as an excellent authority and even referred to him as one of the finest zoologists of his time. It has been rightly recognized that 'Blyth was certainly the founder in this country of a school of what may be called field zoologists. The active correspondence he kept up with the sportsmen-naturalists in various parts of the country, and his elaborate notices of the presentations which were made by them to the Society, not to speak of his numerous Memoirs, contributed an impetus to the study of natural history, which has done more to its extension in India than all the previous publications.'[e]

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[a] Kinnear, p. 770.
[b] Tickell (1), pp. 569–83.
[c] Tickell (2), pp. 32–33.
[d] For details, read about 50 papers published by Blyth in *JASB*.
[e] Bose (P. N.) (1), pp. 62–64.

W. T. Blanford and others

The versatile W. T. Blanford while engaged in geological work spared no efforts in collecting and describing the molluscs, reptiles, birds and mammals. His observation on the birds included those of central, western and southern India, as also the eastern and northern frontiers of Sikkim. He studied in detail the genus *Gymnops* (Lacertidae), the Sind 'Ibex', Markhor, the Indian antelope, *Felis shawiana*, *Golunda elliotti*, *Tracnalopterum*, *Arvicola* and a number of reptiles and amphibia.[a] In England, after retirement, Blanford was appointed the editor of a series of volumes on *The Fauna of British India*. He himself wrote the volume on mammals which was published between 1888 and 1891 as well as two volumes on birds.

To the fields of herpetology and malacology W. Theobald made valuable contributions. He investigated Batrachia, Helicidae and Gastropoda. For about 25 years he was engaged in the study of land and freshwater shells of India and Burma. Theobald also compiled the Catalogue of reptiles in the Museum of the Asiatic Society of Bengal. H. Benson, T. Hunter and W. T. Blanford were the other three investigators in this field. G. Nevil was noted for his study of marine and estuarine mollusca. H. Godwin-Austen described and catalogued a number of birds in various parts of Assam. G. E. Dobson prepared a monograph on the Asiatic *Chiroptera* and was recognized as one of the outstanding authorities on that order of the Mammalia. He studied some new species of *Chiroptera verspertilio*, *Tiaenops persicum*, Rhinolophine bats, *Molossus* and the like. F. Stoliczka devoted himself to a systematic study of the organism in mollusca and various other invertebrates and vertebrates. R. Lydekker is remembered for his studies of the fossil vertebrata of India and deer, antelopes, wild oxen, sheep and goat.[b]

The study of fishes also received due attention. McClelland produced a monograph on the Indian Cyprinidae, while E. Blyth, as noted already, was the author of several papers on fishes. The most remarkable investigators in this field were undoubtedly F. Day and Buchanan Hamilton. The former brought out in two volumes an authoritative account of the fishes of India.

The other noted zoologists who worked in India included A. L. Adams (mammals), Jerdon (wrote *Birds* and *Mammals of India*), Aitchison (mammals), A. O. Hume (mostly birds), Oldfield Thomas (genus *Mus*), G. S. Rodon (bears and the Himalayan game animals) and R. C. Wroughton (rodents).[c]

The scientific staff of the Indian Museum played a leading role in furtherance of zoological investigations which are too many to be described in detail in this short compass. Briefly,[d] a number of zoological notes

[a] Fot details, see about 40 papers published by W. T. Blanford in *JASB*.
[b] This account is based on the papers published in *JASB* and *Proceedings of the Asiatic Society*.
[c] Kinnear, pp. 771–75.
[d] Prashad (2), p. xiv.

were prepared by Atkinson on Rhynchota. Investigations on Lepidoptera (in general butterflies and moths) were carried out by Moore, de Niceville, Wood-Mason and Elwes. T. Anderson worked on the new and little known Asiatic shrews. Spiders and mimic ants were studied by Walsh, and snakes by Sclater. Lt.-Colonel Alcock published a number of papers

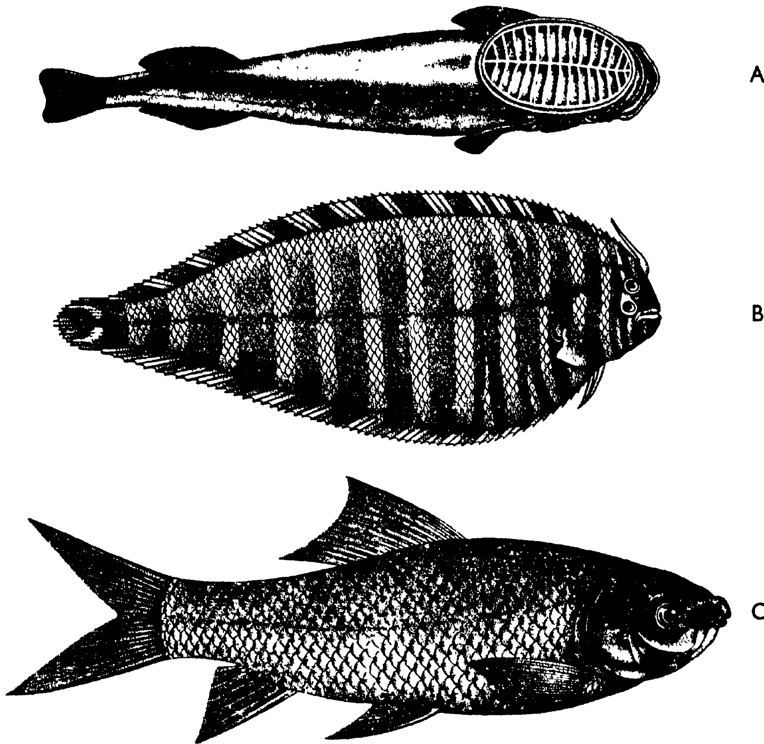


Fig. 10.9. (A) *Echeneis albescens*. (Reproduced from Day, I, Pl. LVII, fig. 2.)
(B) *Synaptura cornuta*. (Reproduced from Day, II, Pl. XCIV, fig. 4.)
(C) *Labeo rohita*. (Reproduced from Day, II, Pl. CXXVII, fig. 4.)

on corals, actinians, crustaceans and other marine animals collected during his voyages on the *Investigator*. In collaboration with Frank Finn, Alcock also conducted investigation into the theory of warning colours (also known as aposometic colouration relating to the gaudy colours of some stinging insects). In addition, Alcock brought out his well-known work entitled *Materials for a Carcinological Fauna of India* (published in six parts from 1885 to 1900) which contains valuable information on marine crabs of the Indo-Pacific region.

In 1871 a committee (with Stoliczka, Blanford, Anderson, Wood-Mason, Oldham and others) constituted by the Asiatic Society recommended that

deep sea dredging in Indian waters be undertaken, and three years later a Marine Survey Department was established by the government. During the period 1874–1881, Armstrong was able to gather marine zoological material from shallow water up to a depth of 100 fathoms. Wood-Mason

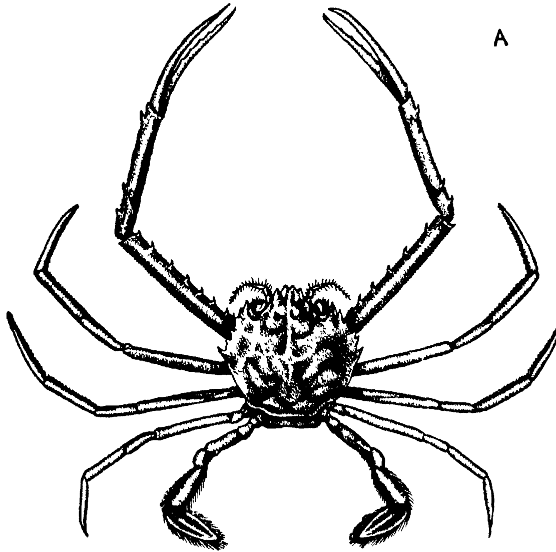


Fig. 10.10. (A) *Lupocyclus strigosus*. (Reproduced from Wood-Mason (J.), Crustacea, Pl. XLVI.)

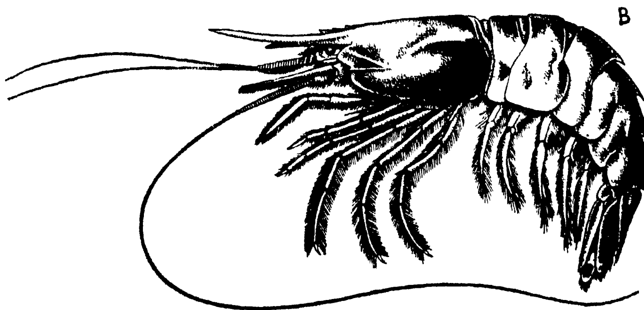


Fig. 10.10. (B) *Acanthephyra armata*. (Reproduced from Wood-Mason, Crustacea, Pl. III.)

undertook deep sea biological investigation in the Andamans and Nicobars. The marine survey vessel, the *Investigator*, with its complete deep sea equipment was active, particularly between 1884 and 1898 in the Bay of Bengal, the mouths of the Ganges and the Persian Gulf. A series of monographs

relating to Hexactinellid sponges, Madreporarian and Alcyonarian corals, Echinoderms, fish and Crustacea appeared.[a]

AGRICULTURAL AND VETERINARY RESEARCH

In the field of agricultural research no significant research programmes seemed to have been undertaken in the nineteenth century. The Famine Commission in 1880 recommended strongly the revival of the departments of agriculture both at the centre and in the provinces for improvement of agriculture and affording famine relief. It was only towards the end of the century that agricultural departments came into existence in a few places like Bombay (1885), Madras (1889), Shillong (1894), Allahabad (1895), Nagpur (1895) and Calcutta (1896).[b] In 1889–1891, J. A. Voelcker, Consulting Chemist to the Royal Agricultural Society, visited India at the invitation of the Secretary of State for India, and submitted a report on the improvement of agriculture in India. In 1903 the Indian Agricultural Institute was established at Pusa in Bihar. The origin of this institute can be traced not only to the recommendation by the Royal Agricultural Commission in 1896, which emphasized researches in agriculture, but also to a generous donation of £20,000 (afterwards raised to £30,000) made by Henry Phipps in 1903 with the request that the amount might be devoted to some object of public utility in India, preferably in the direction of scientific research (a part of this donation was later utilized for the establishment of the Pasteur Research Institute at Coonoor). The Government of India took steps for attaching a farm of some 1,300 acres to the Agricultural Institute for experimental cultivation and demonstration. Some advanced courses in agricultural education were also started in 1908. Consequent upon the earthquake which shook Bihar in 1934, the institute was moved to its present location in Delhi.

The first step towards providing facilities for investigating into diseases of stock in India was taken in 1890 when Linard was appointed as Imperial Bacteriologist at the College of Science at Poona. His important duties included the determination as far as possible by biological research, of the means of preventing and curing such diseases. As the climatic conditions of Poona were not found conducive to such researches, the laboratory was shifted to Mukteswar in 1893.[c] In this laboratory, investigations on rinderpest were undertaken, and in the next five to six years a potent rinderpest serum was developed. Gradually the work on the preparation of anti-serums for anthrax and studies in Black quarter and Mallein were taken up. A course of instruction in tropical veterinary diseases and in serum therapeutics was also started.

[a] Rao (H. S.), pp. 360–61.
[b] Prashad (2), p. xix.
[c] The renowned bacteriologist Robert Koch paid a visit to this laboratory in 1896.

MEDICAL INVESTIGATIONS

Though the medical officers began serving the British Army in India as early as 1754,[a] and in the succeeding years, their number in the Indian Medical Service was steadily on the increase, medical research as such did not take place in India even up to the middle of the nineteenth century. Between 1847 and 1850, however, Edward Hare introduced successfully the practice of administering quinine in fevers. Henry Vanoyke Carter and Crawford made some important dissections and prepared the woodcuts which illustrate Gray's Anatomy. Carter also investigated the origin and development of famine fever, leprosy, elephantiasis and mycetoma. Ronald Ross worked on the origin of malarial fever and P. J. Freyer on the development of the operation of litholapaxy and prostatectomy, while Leonard Rogers conducted investigations on cholera, dysentery and liver abscess.[b]

The now familiar Haffkine Institute at Bombay was started in 1896 as the Plague Research Laboratory, with Dr. Waldemar Mordecai Wolff Haffkine as the Director. It was in 1896 that for the first time the dreadful plague, which probably travelled to India from China, was detected in Bombay in an epidemic form. Haffkine, who was at that time studying prophylactic inoculation against cholera in Bengal, was associated with a committee (constituted by the Government of Bombay) to enquire into this epidemic. Soon the necessity arose for establishing a laboratory for developing an effective vaccine against the disease. With ingenuity Haffkine was able within two months to prepare a broth vaccine against the plague bacilli, with which he carried out the inoculation of about 8,000 people in a few weeks. In 1906 the name of the laboratory where Haffkine worked was changed into Bombay Bacteriological Laboratory and in 1925 to its present name, thus associating with it the name of Haffkine. The laboratory did work on the plague prophylactics, relapsing fever, grumic-worm disease and the like, gradually extending its investigations into the biochemical field also.

ENGINEERING INVESTIGATIONS

Certain types of investigations in engineering were in progress, particularly in the later half of the nineteenth century. The railways, construction of bridges, canal works, lock and dam systems including the regulators and devices for discharge of excess of water, improvement of rivers for navigation, construction of lighthouses, arches and the like, drainage and water supply demanded engineering skill of no mean order. As these had to be accomplished in the Indian conditions, the engineers had to make innovations. The profession of engineering, which was held in esteem, attracted into its fold able men who, amidst their routine, found time, prudently enough, to study not a few of the engineering problems and, in

[a] Crawford, p. 370.

[b] Crawford, pp. 368–69.

the process, made original contributions. Details of such contributions can be noticed in a number of volumes of professional papers, the first of which came out in 1863 from Roorkee, one of the main centres of engineering activity then, under the editorship of J. G. Medley. A special study of these volumes is necessary before an attempt is made to present an authentic account from the point of view of the history as well as achievement of the engineering investigations in India.

ARCHAEOLOGY

Soon after its establishment, the Asiatic Society, under the guidance of William Jones, encouraged antiquarian studies in the classical texts and epigraphs, monuments and other architectural remains of India. Indian epigraphical studies took new strides due mainly to the devoted efforts of H. T. Colebrooke and H. H. Wilson. The impressive architectural remains and several cave paintings received attention of scholars like Malet (Ellora), Salt (Kanhari), Sykes (Ellora), Goldingham (Elephanta), Erskine (Ajanta), Chambers (Mahabalipuram) and Mackenzie (Amaravati), who out of love for the ancient relics of India brought to light their hidden history.[a]

The antiquarian investigations were the forerunners of further efforts in field archaeology, and the latter assumed new meaning as a result of the lead given by James Prinsep. Prinsep also studied the Kharoṣṭhī and the Brāhmī scripts. Markham Kittoe and Alexander Cunningham carried out work on the rock edicts of Asoka at Dhauli, and Dhamek stupa (1834–1835) at Saranath respectively. The latter was probably the earliest excavation of an ancient site in India. Later, Cunningham took up investigations on the Indo-Greek and Indo-Scythic dynasties, and identified the ancient site of Sankisa. Markham Kittoe surveyed the *vihāras* and *chaityas* in Gaya and elsewhere in Bihar, and continued the excavations initiated by Cunningham in the ruins at Saranath.[b, c]

Edward Thomas specially studied the Indian numismatics from about the third century B.C. to the sixteenth century A.D. His work on the South Indian epigraphy is well known. J. Stevenson and Bhau Daji were the others who were engaged in the epigraphical studies in western India. Further, James Fergusson made an extensive architectural survey (1829–1847) of ancient buildings, while Meadows Taylor devoted particular attention to the megalithic tombs.[d]

In 1848 Cunningham emphasized the importance of undertaking an archaeological survey of the country with the support of the government. Realizing the necessity of such a survey, Governor-General Canning established the Archaeological Survey of India in 1861, befittingly with Cunningham as the first Archaeological Surveyor. In the next four years, Cunningham explored an extensive area from Gaya in the east to the Indus in the

[a] Roy (S.), pp. 12–19. [b] Roy (S.), p. 29. [c] Markham, p. 244. [d] Roy (S.), p. 30.

north-west, and from Kalsi in the north to the Dhamnar caves in the south,[a] while Cunningham's explorations were exclusively confined to north India. James Burgess investigated western and southern India.[b, c]

The prehistoric archaeology in India owes its inspiration to the pioneer efforts of H. P. L. Mesurier of the East India Railway (neoliths in the valley of the Tosney river) and Robert Bruce Foote of the Geological Survey (palaeoliths at Pallavaram).[d]

Towards the end of the nineteenth century, the archaeological department underwent some structural changes. In the beginning of the twentieth century, it received the necessary financial support and encouragement from the government, and in the next two to three decades, archaeology established itself in India.

SCIENTIFIC PUBLICATIONS

Admittedly it is almost an impossible task to give an exhaustive account of the scientific publications which came out in India during the nineteenth century in such a short survey as this. But as scientific publications are a reliable index to the nature and structure of the scientific activities in progress, it is perhaps necessary to mention at least the important scientific publications. The transactions of the Asiatic Society continued to come out under the title *Asiatick Researches* till 1839 (first published in 1788; in all 20 volumes). In 1821 Wilson started the *Quarterly Oriental Journal*. This periodical and also the *Transactions of the Medical and Physical Society* carried short notes on important discoveries (which the *Asiatick Researches* by its very form could not publish). Both these stopped publication in 1827. The demand for this serial was so great that more than one pirated edition was printed in Europe then. As stated already, on the efforts of James Prinsep (Secretary of the Asiatic Society), the *Journal of the Asiatic Society of Bengal* was started in 1832. Though largely devoted to literary publications, the *Journal* used to publish scientific papers also and superseded the *Asiatick Researches*. Between 1832 and 1904, as many as 75 volumes in two parts each (with several supplementary numbers) were published. From 1834 to 1847, the *Indian Review and Journal of Foreign Science* was published at Calcutta.

In the field of medicine, there were a number of publications. Among them mention may be made of *Transactions of the Medical and Physical Society* (Calcutta: 1825–1845); *Indian Journal of Medical Science* (Calcutta: 1834–1836); *Indian Annals of Medical Science* (Calcutta: 1853–1877); *Madras Quarterly Journal of Medical Science* (Madras: 1860–1868); *Indian Medical Gazette* (Calcutta: 1866 onwards); *Madras Monthly Journal of Medical Science* (Madras: 1870–1873); and *Scientific Memoirs by the Medical Officers of the Army of India* (Series: 1885).[e]

[a] Markham, pp. 262 ff.
[b] Black, pp. 320–72.
[c] Markham, p. 271.
[d] Roy (S.), p. 39.
[e] Prashad (2), p. xvi.

In zoology, several valuable publications in series appeared in the last three decades of the nineteenth century. *Birds of India* (by T. C. Jerdol, 1862–1863); *Stray Feathers* (I–XI; edited by Hume, 1873–1888); *Indian Lepidoptera* (by Hewitson and Moore, 1879–1888); *Game Birds of India, Burma and Ceylon* (by Marshall, 1879–1881); *Butterflies of India, Burma and Ceylon* (by Marshall and de Niceville, 1882–1890); *Natural History of the Mammalia of India and Ceylon* (by Sterndale, 1884); *Avifauna of the British India* (by Murray, 1888–1890); a number of the Descriptive Catalogues of the collections of the Indian Museum; and *Reports of the R.I.M.S. Investigator* (started in 1887); *Fauna of British India* (edited by W. T. Blanford, 1888; the first of the series to be published by the authority of the Secretary of the State for India); and *Fishes of India* (by F. Day, 1875–1878) deserve special mention.[a] In addition, the *Journal of the Bombay Natural History Society* began to appear from 1886.

As to geology, the *Memoirs* pertaining to the completed surveys and mineral investigations (started in 1856 and issued from time to time), *Palaeontologia Indica* (started in 1861) and the *Records* (started in 1868 as an annual) merit particular attention. Further, the detached papers and reports, which had been accumulating since 1851, were collated in three volumes: vols. I and II by H. B. Medlicott and H. F. Blanford; and vol. III by V. Ball and F. P. Mallet.

Some noteworthy publications in botany have been indicated already. They related to the works of Roxburgh, Wallich and George King. As has been seen, the Botanical Survey of India began to publish the *Annals* from 1887 due to the efforts of King who also published a series of papers on the Flora of the Malay Peninsula (1889–1896). His successor David Prain brought out a series under the title 'Noviciae Indica' (1889–1898). Barclay of the Bengal Medical Service published another series on the parasitic Rust Fungi (of the order Uredinae), between the years 1886 and 1891.[b]

In meteorology, *Memoirs* (started by H. F. Blanford in 1876), *Indian Meteorologist's Vade Mecum* and *Climate of India, Burma and Ceylon* by Blanford; *Handbook of Cyclonic Storms in the Bay of Bengal* and *Climatological Atlas* by Eliot deserve special mention. Apart from the foregoing there were a number of other publications including periodicals relating to different branches of science published by the newly formed societies as well as some government organizations in the last quarter of the nineteenth century.

SCIENTIFIC AND TECHNICAL EDUCATION

Education in India in the early part of the nineteenth century was neither widespread nor designed towards the promotion of science as well as technical arts and crafts. A few centres of learning then functioning in Bengal, Bombay and Madras were largely concerned with traditional learning and narrow scholasticism. In the first two decades of the century a number of missionary schools sprang up in and near Calcutta as well as

[a] Prashad (2), p. xiv.

[b] Prashad (2), p. xv.

in the Presidencies of Bombay and Madras. The distressing fact was that all those institutions, besides being ill equipped, did not attempt to enthuse the young minds to develop a rational spirit beyond the confines of the traditional ideas.

Minto's Remarks

Lord Minto in his minute on the subject of education in India observed in 1811 as follows: 'It is a common remark that science and literature are in a progressive state of decay among the natives of India. From every inquiry which I have been enabled to make on this interesting subject, that remark appears to me but too well founded. The number of the learned is not only diminished, but the circle of learning, even among those who still devote themselves to it, appears to be considerably contracted. The abstract sciences are abandoned, polite literature neglected, and no branch of learning cultivated but what is connected with the peculiar religious doctrines of the people. The immediate consequence of this state of things is, the disuse, and even actual loss, of many valuable books; and it is to be apprehended, that unless government interpose with a fostering hand, the revival of letter may shortly become hopeless, from want of books, or of persons capable of explaining them.

'The principal cause of the present neglected state of literature in India is to be traced to the want of that encouragement which was formerly afforded to it by princes, chieftains, and opulent individuals under the native government. Such encouragement must always operate as a strong incentive to study and literary exertions, but especially in India, where the learned professions have little, if any, other support. The justness of these observations might be illustrated by a detailed consideration of the former and present state of science and literature at the three principal seats of Hindoo learning, viz. Benares, Tirhoot and Nuddea. Such a review would bring before us the liberal patronage which was formerly bestowed, not only by princes and others in power and authority but also by the zamindars, on persons who had distinguished themselves by the successful cultivation of letters at those places. It would equally bring to our view the present neglected state of learning at those once-celebrated places; and we should have to remark with regret that the cultivation of letters was now confined to the few surviving persons who had been patronized by the native princes and others, under the former governments, or to such of the immediate descendants of those persons as had imbibed a love of science from their parents.

'It is seriously to be lamented that a nation particularly distinguished for its love, and successful cultivation of letter in other parts of the Empire, should have failed to extend its fostering care to the literature of the Hindoos and to aid in opening to the learned in Europe the repositories of that literature.'[a]

[a] Sharp, p. 19.

The Charter of 1813

In Britain then attempts were being made by some enlightened members of Parliament to make the East India Company assume legal responsibility for educating the Indians. In 1813 when the Charter was renewed, a clause was introduced which stated thus: 'And be it further enacted, that it shall be lawful for the Governor-General in Council to direct that out of any surplus which may remain of the rents, revenues, and profits arising from the said territorial acquisitions, after defraying the expenses of the military, civil, and commercial establishments, and paying the interest of the debt, in manner hereinafter provided, a sum of a not less than one *lac* of rupees in each year shall be set apart and applied to the revival and improvement of literature, and the encouragement of the learned natives of India, and for the introduction and promotion of a knowledge of the sciences among the inhabitants of the British territories in India; and that any schools, public lectures, or other institutions, for the purposes aforesaid, which shall be founded at the Presidencies of Fort William, Fort St. George, or Bombay, or in any other parts of the British territories in India, in virtue of this Act, shall be governed by such Regulations as may from time to time be made by the said Governor-General in Council; subject, nevertheless, to such powers as are herein vested in the said Board of Commissioners for the Affairs of India, respecting colleges and seminaries; provided always, that all appointments of offices in such schools, lecturerships, and other institutions, shall be made by or under the authority of the governments within which the same shall be situated.'[a]

Mahāvidyālaya

For various reasons, however, the proposal could not be implemented for a decade. In 1816 the reputed social reformer Raja Ram Mohan Roy started a school at Suripara in Calcutta for teaching the Hindu boys in English. In May 1866 some liberal-minded gentlemen of Calcutta including David Hare (an ordinary watch-maker by profession but a great philanthropist), Raja Ram Mohan Roy, the Raja of Burdwan, Raja Radha Kanta Deb and Sir Hyde East, the then Chief·Justice of the Supreme Court, collected over a lac of rupees, and on 20 January 1817 founded a 'Seminary for the instructions of the sons of the Hindus in the European and Asiatic languages and sciences'. The subjects taught included arithmetic, astronomy, chemistry and natural philosophy. It was indeed a rare institution divided into two sections—a school which imparted instructions in English, Bengali, grammar and arithmetic, and a college in which were taught, besides the languages, the sciences including astronomy, mathematics and chemistry. A fact of great significance was that teaching of English was given an important place in this institution which was named at that time the *Mahāvidyālaya* or *Mahāpāṭhaśālā*.[b] Later it became the Hindu College

[a] Sharp, p. 22.

[b] Dhar, pp. 128–36.

and also the nucleus of the present Presidency College at Calcutta. Of particular significance is the fact that the Hindu College nourished young men who subsequently devoted themselves to the spread of English education. In the beginning the institution had a strength of only 20 students and for several years the number did not exceed 70. Between 1817 and 1824 the institution was managed entirely by a joint committee of Europeans and Indians. According to the progress report of the institution (1827–1828), the studies included natural and experimental philosophy, chemistry, mathematics, algebra, Tytler's *Elements of General History*, Russel's *Modern Europe*, works of Milton and Shakespeare, the number of students being 436.[a]

Soon the *Vidyālaya* ran into financial difficulties and when the pecuniary aid from the government was sought, the latter thought it wise to exercise some control over the affairs of the institution. Thus was appointed H. H. Wilson as Visitor to the *Vidyālaya* to represent the General Committee of Public Instruction. The institution had already earned the remark of the General Committee of Public Instruction (1831) that 'a command of English language and a familiarity with its literature and science had been acquired (by this institution) to an excellence rarely equalled by any school in Europe. A taste for English has been widely disseminated and independent schools conducted by young men reared in the *Vidyālaya* are springing up in every direction'.

The General Committee[b] itself was set up by the East India Company in 1823 to promote the objectives of the Clause of the renewed Charter of the Company. The Committee had ten members and the great Oriental scholar H. H. Wilson was its Secretary. As it happened the Committee sought to encourage Oriental learning in preference to the 'useful knowledge' (sciences). The Committee's attempt met with a wave of disapproval at home and in England.

Raja Ram Mohan Roy's Petition

At home, Raja Ram Mohan Roy exhorted Governor-General Lord Amherst to encourage instruction in scientific subjects, and not 'to lead the minds of youths with grammatical niceties and metaphysical distinctions of little or no practical use to the possessors or to society'. In his historic petition to the Governor-General, Ram Mohan Roy emphasized as follows: 'Humbly reluctant as the natives of India are to obtrude upon the notice of government the sentiments they entertain on any public measure, there are circumstances when silence would be carrying this respectful feeling to culpable excess. The present rulers of India, coming from a distance of many thousand miles, to govern a people whose language, literature, manners, customs, and ideas which are almost entirely new and strange to them, cannot easily become so intimately acquainted with

[a] Mahmood, p. 26.

[b] Sinha, p. 53.

their real circumstances as the natives of the country are themselves. We should, therefore, be guilty of a gross dereliction of duty to ourselves, and afford our rulers just ground of complaint at our apathy, did we omit, on occasions of importance like the present, to supply them with such accurate information as might enable them to devise and adopt measures calculated to be beneficial to the country, and thus second by our local knowledge and experience, their declared benevolent intentions for its improvements.

'The establishment of a new Sanskrit School in Calcutta evidences the laudable desire of government to improve the natives of India by education—a blessing for which they must ever be grateful; and every well-wisher of the human race must be desirous that the efforts made to promote it should be guided by the most enlightened principles, so that the stream of intelligence may flow in the most useful channels.

'When this seminary of learning was proposed, we understood that the government in England had ordered a considerable sum of money to be annually devoted to the instruction of its Indian subjects. We were filled with sanguine hopes that this sum would be laid out in employing European gentlemen of talents and education to instruct the natives of India in mathematics, natural philosophy, chemistry, anatomy and other useful sciences, which the nations of Europe have carried to a degree of perfection that has raised them above the inhabitants of other parts of the world.

'While we looked forward with pleasing hope to the dawn of knowledge thus promised to the rising generation, our hearts were filled with mingled feelings of delight and gratitude; we already offered our thanks to Providence for inspiring the most generous and enlightened nations of the West with the glorious ambition of planting in Asia the arts and sciences of modern Europe.

'We find that the government are establishing a Sanskrit School under Hindu Pandits, to impart such knowledge as is already current in India . . . This seminary (similar in character to those which existed in Europe before the time of Lord Bacon) can only load the minds of youth with grammatical niceties and metaphysical distinctions, of little or no practical use to the possessors or to society. The pupils will thereby acquire what was known two thousand years ago, with the addition of vain and empty subtilties since produced by speculative men, such as is already commonly taught in all parts of India.

'The Sanskrit language, so difficult that almost a lifetime is necessary for its acquisition, is well known to have been, for ages, a lamentable check on the diffusion of knowledge; and the learning, concealed under this almost impervious veil, is far from sufficient to reward the labour of acquiring it . . .'[a]

In England, the Court of Directors of the East India Company reprimanded the Committee by saying that 'it was encouraging a great deal of what was frivolous and mischievous in Oriental learning'.[b] There also

[a] Sharp, pp. 101–102.

[b] Sharp, p. 92.

ensued between the two groups of members of the Committee the well-known controversy between the Anglicists (who were supporters of English and Western education) and the Orientalists (who sought to promote oriental learning in classical languages).

English Education

At that time Lord Macaulay came to India (1834) and Lord William Bentinck was the Governor-General in Council. Macaulay as the President of the General Committee recommended (in February 1835) the use of English as medium of instruction and the promotion of Western learning. He said: 'I think it is clear that we are not fettered by pledge expressed or implied; that we are free to employ our funds as we choose; that we ought to employ them in teaching what is best worth knowing; that English is better worth knowing than Sanskrit or Arabic; that the natives are desirous to be taught English, and are not desirous to be taught Sanskrit or Arabic; that neither as the languages of law nor as the languages of religion have Sanskrit and Arabic any peculiar claim to our encouragement; that it is possible to make the natives of this country thoroughly good English scholars, and that to this end our efforts ought to be directed.'[a] Bentinck (in March 1835) directed that all funds be employed for imparting to the native population a knowledge of English literature and science through the medium of English language and that no portion of it should be expended on the printing of Oriental works. Nevertheless, as before, a knowledge of English literature and science was not to be imparted on a massive scale, for it was meant for the upper classes who in turn were expected to 'filter it down to the masses'. In the next two years twelve new schools were started in the Bengal Presidency alone. The public response for English education was on the increase. By 1838, there were some six thousand pupils taking up new courses in English. Governor-General Lord Hardinge declared in a resolution (1844) thus: 'In every possible case a preference shall be given in the selection of candidates for public employment to those who have been educated in institutions thus established, and specially to those who have distinguished themselves therein by more than ordinary degree of merit and attainment.'[b]

In the Presidency of Bombay, a society for the promotion of education was formed in 1815 and it established schools in Bombay, Surat, Thana and Broach. Chaplain, who was Commissioner in the Deccan, founded the Hindu College at Poona in 1821 and the course of instruction at this college included mathematics, astronomy and medicine. However, it was the then Governor of Bombay, Monstaurt Elphinstone, who gave a significant direction to the growth of education in the Bombay Presidency. He encouraged Vernacular education while English was taught as one of the languages. Later the Bombay Board of Education, created in 1840, took active steps towards the promotion of English education in the Presidency.

[a] Sharp, p. 116. [b] Sharp, p. 90.

In Madras, the spread of English education was not so rapid at the beginning of the nineteenth century. However, the missionary schools were very active imparting general education. It appeared that the Christian missionaries were more successful there among the Tamil population than in any other part of India. The Protestant Mission, under the patronage of the Society for Promoting Christian Knowledge, which established schools at Madras, Tanjore and Trichinopoly, continued to be active. A few more schools were founded at Palamcottah, Thirunelveli, Ramanathapuram and Sivaganga. But the Committee of Public Instruction which was constituted in 1826 as a result of the efforts of Sir Thomas Munro was not so active as it was expected to be. The Court of Directors in their Despatch of September 1830 enjoined: 'We wish that there should be an English teacher at each institution who should not only give instruction in the English language but who may likewise be capable of assisting the students in the study of European science.'

By and large in the three Presidencies, the position with regard to general education including courses in science was far from being satisfactory. In the meantime, the Orientalists continued to take energetic steps to promote oriental learning. Conflicting views and disproportionate efforts, which appeared to raise their heads now and then, seemed to be detrimental to the spread and growth of the new knowledge including scientific subjects.

Establishment of Universities

In the history of education in India, the year 1854 is important, for in that year came out the famous Educational Despatch of Charles Wood (later Lord Halifax) who was then the President of the Board of Control. The Wood's Despatch had as its primary object 'the diffusion of the improved arts, science, philosophy and literature of Europe; in short of European knowledge'. It also recommended the creation of the departments of Public Instruction in Bengal, Madras, Bombay, the North-Western Provinces and the Panjab, each under a Director of Public Instruction. With this machinery the general education, and as a part of it science education, was to be imparted on a massive scale. In addition, three universities were to be established on the model of London University. Even though Wood recognized that the education of the country's rural population should be the direct responsibility of the government, he wanted the universities 'to place the benefits of education plainly and practically before the higher classes in India'.

The three universities, which were established at Calcutta[a] (January 1857), Bombay (July 1857) and Madras (September 1857), were only affiliating and examining bodies in the Faculties of Law, Science, Civil Engineering,

[a] Even in 1845, the Council of Education submitted a proposal for the establishment of a university in Calcutta. But this proposal did not meet with the approval of the Court of Directors in England.

Medicine and Surgery, besides Arts. They were noticeably active in promoting collegiate education in different places and at different levels. The growth of educational institutions and the studentship between 1860 and 1892 may be summarized thus:[a]

	1860–1861		1870–1871		1881–1882		1891–1892	
	No. of Instt.	Students	No. of Instt.	Students	No. of Instt.	Students	No. of Instt.	Students
Art colleges including Oriental colleges ..	17	3,182	44	3,994	67	6,037	104	12,985
Professional colleges ..	8	679	19	2,126	18	1,545	37	3,292

The administrative exigencies of the East India Company demanded the employment of engineers and doctors for its engineering and medical services in subordinate positions, even though on a small scale. For its calculated exploitation of the natural resources of India and also for the maintenance of its own personnel on the one hand and political as well as economic influences on the other, the Company could not but establish the minimum number of engineering and medical institutions.

Engineering and Allied Technical Education

As has been stated already, Madras possessed a survey school even towards the close of the eighteenth century (1794) started by Michael Topping, the East India Company's Astronomer and Geographical Marine Surveyor at the Presidency of Fort St. George. The school, which passed through vicissitudes from time to time, trained a number of apprentices who were taught, in a course extending to 1½ year, subjects like algebra, mensuration, building-construction, surveying, plan drawings, etc. In 1842 an attempt was made to establish a college of engineers, and it took concrete shape only in 1855 due to the encouragement of A. J. Arbuthnot who was Director of Public Instruction in the Madras Presidency. This college became the civil engineering college in 1859, and in 1877 was affiliated to the Madras University. From 1880 onwards the college registered rapid progress and emerged as one of the best engineering institutions in the country.

As early as 1848, Governor-General Lord Dalhousie suggested that each of the three Presidency towns should have an engineering college. But it was only in 1856 that an engineering college could be started at

[a] *Imperial Gazetteer of India*, IV, p. 455.

Calcutta, which was affiliated a year later to the Calcutta University. For some years it was associated with the Presidency College and, in 1880, it was shifted to its present quarters at Sibpur near Calcutta. The college, which imparted instruction mainly in civil engineering to students mostly from Bengal, Orissa, Bihar, Burma and Assam, had also a mechanical testing laboratory and a mining section.

In the Bombay Presidency, Elphinstone founded at Bombay in 1821 an engineering institution which developed later into a college. In 1854 Poona had an engineering school to provide education for subordinate officers of the Public Works Department. The institution which became a college in 1856 was later affiliated to the Bombay University. In the beginning there was no system of levying tuition fee; instead scholarships were awarded with guarantee of appointment for successful candidates. It was only in 1870 that tuition fee was levied for the first time.

It may be noted that the aforesaid engineering institutions offered only licentiateship courses till 1880 when they began to run both degree and licentiateship courses. They were well equipped, and on the theoretical side, the instruction was stated to be on par with that in England at that time.

In 1847, after the conclusion of the First Panjab War, steps were taken to implement the construction of the Ganges Canal. Some large workshops sprang up at Roorkee for that purpose. James Thomason, Lieutenant-Governor of North-Western Provinces, proposed the establishment of a college to supply trained engineers for the employment in the Upper Ganges Canal Project. In 1853 Thomason died, and a year later his name was befittingly associated with this college.[a] In 1864 it was affiliated to the Calcutta University. The courses offered at the college were at three levels, viz. (i) engineer class; (ii) upper subordinate class and (iii) lower subordinate class. The instructions were of a high order and the engineers turned out by this college were in great demand.

Industrial Schools

In the Presidency of Bombay, a school of industry was established early in 1879 at Ratnagiri. Later another came into being in Byculla. Further, there were three other minor industrial schools, while attempts were also made to have a network of industrial schools under the Municipal Boards.

At Madras, an industrial school named the School of Ordinance Artificers was opened in 1840 by Major Maitland, Superintendent of the Gun-carriage Manufactory.[b] Yet another institution known as the School of Industrial Arts was opened in 1850 by Hunter, a medical man by profession, 'with the liberal and enlightened design of creating among the native population a taste for the humanizing culture of the fine arts'. Hunter also started another school of industry (1851) 'in order to afford to the rising generation of the country the opportunity and means of acquiring

[a] Richey, p. 357.

[b] Richey, p. 344.

useful handicrafts'. The two schools were amalgamated under the name of School of Industrial Arts which was taken over by the government in 1855. In 1886 there were six industrial schools in the Presidency, three in Madras and three in the mofussil. The average attendance at the schools in Madras was about 60, while the total number of students of the technical schools and colleges in that year was less than 1,000, out of a total of about four and a half lakhs of students.[a]

In 1887 the Victoria Jubilee Technical Institute at Bombay started courses in electrical, mechanical and textile engineering. The engineering institutions whose number rose to 12 by the end of the nineteenth century were supplying qualified men to meet the demands for constructing buildings, roads and canals. In addition, there were some technical schools engaged in the training of craftsmen. Needless to add that they were being run in such a way as to be in line with the commercial interests of the British Government.

In Bengal, the Calcutta School of Arts offered courses which were comparable with that of any school of art in England; and there were as many as 157 students receiving training in 1886. In the North-Western Provinces and Oudh, there was practically no school of art worth the name even by the close of the nineteenth century. However, there were two industrial schools at Gorakhpur and Banaras, a survey school at Calcutta (1879) and a school of engineering at Bankipur in Bihar (1896). An interesting development was the establishment at Dehra Dun of the Imperial Forest School in 1878–1881 for the technical training of executive forest officers, with the courses extending over 18 to 21 months.[b]

Position of Technical Education in India (1884–1885)[c]

	University level		School level					Technical classes in High Schools	
	Med.	Engg.	Art	Med.	Engg. and Survey	Industrial	Agri.	Art	Agri.
Institutions	3	4	4	17	20	45	26	36	8
No. of pupils	533	218	655	1,040	755	1,379	142	2,171	289

It must, however, be stated that the government was not blind to the importance of technical education for training the requisite number of technicians for industrial employment. But the economic policies pursued

[a] *Technical Education in India*, p.10. [b] *Op. cit.*, pp. 18–19. [c] *Op. cit.*, p. 5.

by the government at that time did not help the flow of capital leading to active industrial establishments which could, in turn, employ technicians. In 1888 the Government in a resolution stated as follows: 'Technical education proper is the preparation of man to take part in producing efficiently some special article of commercial demand. It is the cultivation of the intelligence, ingenuity, taste, observation, and manipulative skill, of those employed in industrial production so that they may produce more efficiently. And thus technical education of the special, as contradistinguished from the preparatory kind, is an auxiliary of manufacture and industrial capital. In India at the present time the application of capital to industry has not been developed to the extent which in European countries has rendered the establishment of technical schools on a large scale with the required success. But the extension of railways, the introduction of mills and factories, the exploration of mineral and other products, the expansion of external trade, and the enlarged intercourse with foreign markets, ought in time to lead to the same results in India as in other countries, and create a demand for skilled labour and for educated foremen, supervisors and managers. '*It may be conceded that the effect of these various influences on an Asiatic people is very gradual, and that it would be premature to establish technical schools on such a scale as in European countries, and thereby aggravate the present difficulties by adding to the educated unemployed a new class of professional men for whom there is no commercial demand.*'[a] The result of such a policy was that technical and managerial staff of even the well-developed industries like cotton, jute and coal consisted of only foreign technicians for a fairly long time.

Medical Education

Medical education had a humble beginning in the first quarter of the nineteenth century. As stated already, the study of indigenous systems of medicine was part of the teaching course at the Madrassah (Calcutta) and the Sanskrit College (Banaras). In 1822 a 'Native Medical Institution' was established at Calcutta, which offered a three-year course through the medium of Urdu. In this institution which had in the beginning about twenty students, there used to be only one lecturer who delivered medical lessons in the native language. The dissection practised was that of the 'inferior animals'. In 1826 the Sanskrit College at Calcutta was running medical classes on orthodox lines, using wax models for teaching anatomy, and the instruction was in the native language. Even this attempt did not last a decade. Another effort made by Elphinstone to have a medical institution in Bombay in the same year also ended in a failure after it had been in existence for about six years.

The Bengal Presidency was the first to have had an organized medical service. Perhaps, for this reason Calcutta had the honour of having the first modern medical college for teaching western medical science through

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[a] *Technical Education in India*, p. 36.

the medium of English.[a] In 1833 Lord William Bentinck appointed a committee to examine the state of medical education which was being imparted then in Calcutta. The committee recommended the establishment of an institution, in which 'the various branches of medical science cultivated in Europe should be taught and as near as possible on the most approved European system'. Soon the Native Medical Institution was abolished and, as a result, a medical college came into being in 1835 with the main object of producing sub-assistant surgeons for employment in military and civil stations in India. Dr. M. J. Bramley was appointed as the Superintendent with Drs. H. H. Goodeve, Nathaniel Wallich and W. B. O'Shaughnessy on the teaching staff. It was Goodeve who introduced human dissection in the course of studies for the first time in India. Later he also arranged for advanced instructions in England for the bright medical graduates.

In the new institution, dissection of human body was undertaken by the students. One Madhusudan Gupta was the first to dissect a human body in 1836 to the booming of the guns at the Fort William to mark the occasion. 'It had needed some time, some exercise of the persuasive art, before Madhusudan could bend up his mind to the attempt; but having once taken the resolution, he never flinched nor swerved from it. At the appointment hour, scalps in hand, he followed Dr. Goodeve into the godown where the body lay ready.' Apart from dissection, students were also taught to observe actually the diagnosis and treatment of diseases in the local hospitals. In 1838 a ward with 20 beds and an attached out-patients' department served as the nucleus of the first hospital, and in 1840, the first lying-in hospital with 100 beds was constructed in the college grounds.[b]

In March 1844 the first batch of four Indian students (Bhola Nath Bose, Gopal Chandra Seal, Dwaraka Nath Bose and Surji Coomar Chuckerbutty) was sent to England for medical training under the guidance of Dr. Goodeve in the University College of London. In 1845 the course of instruction was remodelled so as to be within the stipulated conditions of the Royal College of Surgeons of England and of the Apothecaries' Society of London. The period of study was also extended to five years. In a decade the Medical College received recognition of the Royal College of Surgeons of England and the University of London (1846). In 1850 it had as many as 8 professorial chairs (anatomy, chemistry, materia medica, medical jurisprudence, surgery, medicine, midwifery and ophthalmic surgery). In the next year was introduced a three-year course of medical training with a view to training subordinate doctors for serving in the civil hospitals and jails. In 1857 the Medical College was affiliated to the newly established University of Calcutta. Later were added to the college, chairs in dentistry (1861) and hygiene (1864). As the institution became oversized, the apothecary and the licentiate classes were taken out and a new medical

[a] Richey and Sharp, pp. 312–15.

[b] *Souvenir*, p. 70.

school started in 1873. In the last quarter of the nineteenth century the college was indeed in a flourishing state attracting to its fold students from far and wide. What is more, in 1892 the medical degree of the Calcutta University was recognized by the General Medical Council of Great Britain.[a]



FIG. 10.11. The first four Indian medical graduates who went to London. (Reproduced from the *Centenary of Medical College*, p. 26.)

At Madras, a medical school was established in 1843, even though the establishment of such a school for the training of the medical apprentices of European descent and also of native medical pupils for the military subordinate service was sanctioned as early as 1835. In 1846 a chair in chemistry and materia medica was added to the school. In 1851 the school was raised to the status of a college which in 1855 received recognition by the Royal College of Surgeons of London.[b] The Medical College, which was subsequently affiliated to the Madras University, had two sections, the senior one which led to degree level, and the junior one intended for the education of apothecaries and licentiates. The Surgeon of the General Hospital, Madras, was in charge of the college. In 1846 four professorships were sanctioned for anatomy, physiology, midwifery and ophthalmology.

In the Presidency of Bombay, Governor Sir Robert Grant initiated steps in 1837 for the establishment of an institution for medical education.[c] In his honour after his unfortunate death in 1838, sanction was duly accorded

[a] *Souvenir*, pp. 70–72. [b] Richey, p. 330. [c] Richey, p. 335.

to the establishment of a medical institution, and thus came into being in Bombay in 1845 the Grant Medical School to which was accredited the Sir Jamshedji Jeejeebhoy Hospital as the 'School of Practice'. From 1851 onwards new departments were added to this institution which, in 1854, received recognition from the Royal College of Surgeons. Later the institution was affiliated to the Bombay University (1860) as a college for training of graduates as well as apothecaries. In the last two decades of the nineteenth century, the Government adopted liberal policies as a result of which the Grant Medical College established itself on sound lines.

The three medical colleges in the three Presidencies were found inadequate to meet the demand of medical personnel of the times. Steps were, therefore, taken for the establishment of 28 medical schools, with short courses, in different parts of the country such as those at Agra (1853), Nagpur (1867), Sealdah (1873), Dindigul and Patna (1874), Nellore (1876), Cuttack (1876), Indore (1878), Tanjore (1883), Ludhiana (1894) and Dibrugarh (1900).[a]

In 1855 was created what was designated as the *Countess of Dufferin Fund* with the avowed object of providing medical education to Indian women in a college staffed entirely by women. The effort resulted in the establishment of the first medical college for women in 1916, and that was in Delhi.[b]

Agricultural Education

Agricultural education did not appear to have received sufficient attention in the beginning of the nineteenth century, as there did not seem to be distinctly separate institutions imparting agricultural education. Madras had an agricultural farm (estd. 1854) to which was attached a school of agriculture in 1886. The engineering college at Poona (Kirkee), too, had an agricultural wing (1879). The importance of agricultural education was stressed by the Agricultural Conference held in 1888. A year later Dr. J. A. Voelcker, of the British Royal Agricultural Society, made a number of suggestions in order to improve upon the agricultural education and practices. Even so it was only in 1897 that the government accorded the rightful place to agricultural education in the same way as it did for the other subjects.

In the closing decade of the nineteenth century agricultural schools were opened in Coimbatore, Nagpur and Kanpur. The Sibpur Engineering College also developed an agricultural wing, while the Madras Agricultural School soon became a college. However, it was the Bombay University which was first to recognize agriculture as a separate subject for degree examination. Even so, it was only in 1905 that steps were taken for starting an agricultural college at Poona.

Veterinary science also received its attention. The Indian Cattle Plague Commission which was appointed in 1869 made recommendations

[a] Crawford, II, pp. 433–51. [b] Khanolkar, pp. 2–3.

leading to the establishment of veterinary colleges at Babugarh (1877), Lahore (1882), Bombay (1886), Madras and Calcutta (1893). Towards the close of the last century, veterinary services and associated research establishments were organized. However, it may be observed in this connection that as early as 1799 surgeons trained in the veterinary college at London were already in service in India and engaged in the studies relating to the breeding of cavalry horses.[a]

The Trends

The following figures give an insight into the turns and trends in the field of scientific education in the last two decades of the nineteenth century. In 1882 out of 18 professional colleges, there were 12 for law (Bengal leading with 7) and only three each for medicine and engineering. In the succeeding decade the number of arts colleges rose from 67 to 104 and law colleges from 12 to 27, while the number of medical and engineering colleges increased each by one only, from three to four (1892–1893). Further, out of over 16,000 students in 1892–1893, there were less than 2,000 taking up law, 800 medical and 500 engineering.

The after-career of the Indian graduates between 1871 and 1882 can be understood by the following figures (based on the Statistical Reports for the corresponding years):[b]

Province	Number of graduates	Number entering service	Legal profession	Medical profession	Engg. profession
Bengal ..	1,696	534	471	131	19
Bombay ..	625	324	49	76	28
Madras ..	808	296	126	18	–
NW. Provinces	130	61	33	–	6
The Panjab ..	38	21	5	–	–
C.P. ..	14	8	–	–	–
TOTAL ..	3,311	1,244	684	225	53

It will be observed that, in the course of 10 years, out of over 3,000 students, hardly nine per cent took to medical and engineering profession. The first preference was suitable lucrative jobs in government; the next was legal profession, equally lucrative.

[a] Dutta (S.), p. 1.

[b] Mahmood, p. 102.

Organizationally also by the end of the nineteenth century the universities, five in number, continued to be examining bodies. They were to await the Indian Universities Act of 1904 to provide for postgraduate teaching and research in both arts and science. Even towards the close of the century there was no organized system of technical education in India. In effect the attitude of the government towards the promotion of scientific and technical education was one of indifference, and at times of direct antagonism.

Towards the close of the nineteenth century there were about 170 colleges, mostly concentrated in large cities, which did not appear to have been established according to a well-conceived plan. There were as many as 22 colleges in Calcutta, 14 in Madras and two to three in each of the cities like Allahabad, Nagpur, Dacca, Bombay and Poona. The relationship between the colleges and the universities did not seem to be as intimate as it should have been. It was only the Universities Act of 1904,[a] which came out during the time of Lord Curzon, that sought to bring about a direct relationship between them. It was again Curzon who realized the importance of technical education in relation to industrial development. Above all, science could become a separate study only in the first decade of the twentieth century, as indicated later.

THE NEW LEADERSHIP

The sustained work of the scientific service organizations on the one hand and the growth of scientific education on the other, despite their inherent deficiencies and the rather limited spheres of activity, did not fail to stimulate the Indian intellectuals, who received scientific training, to engage themselves in scientific investigations on their own. As a result, the last quarter of the nineteenth century witnessed some Indians who came forward either to establish scientific institutions or to conduct scientific researches with great zeal and devotion. Even the government scientific establishments began to realize the scientific capabilities of the Indians. Thus interest in modern science in India assumed a new dimension in the last two decades of the nineteenth century. Apart from the well-known fields of investigation in the natural sciences, mathematics and physical sciences appeared also as enchanting fields of research to the emerging university graduates, some of whom made noteworthy contributions even in a short time.

Asutosh Mookerjee

In the field of mathematics, Asutosh Mookerjee (1864–1924),[b] who became later the architect of the University of Calcutta, made important contributions. Even as a student, at the age of sixteen, he wrote his first paper which dealt with a new proof of the 25th proposition of the First

[a] Orange, pp. 5–6.

[b] *Souvenir*, pp. 32–34.

Book of Euclid. It appeared in 1881 in the *Messenger of Mathematics* of Cambridge under the title: 'On a Geometrical Theorem'. While a student he gave a new method for solving Euler's equation based on the properties of ellipse. Unfortunately he could not find any suitable guide for his researches at that time. In 1887 he took up the study of Monge's differential equation to all conics, and published four papers in that field. His other papers included those on isogonal trajectories, hydrodynamics and the determination of certain means of elliptic functions.

Jagadish Chandra Bose

The first Indian contribution to physics was by Jagadish Chandra Bose,[a] and that was in 1895. As Professor at the Presidency College, Calcutta, J. C. Bose's researches were concerned with electric waves and their interaction with matter.

Bose devised his own instruments with great ingenuity and, with the help of them, succeeded in generating waves which had much smaller wavelengths (a few millimetres—from 25 mm to 5 mm). He also investigated the quasi-optical properties of these waves, such as refraction, total reflection, polarization, and rotation of the plane of polarization. His first scientific publication entitled 'On Polarization of Electric Waves by Double Refracting

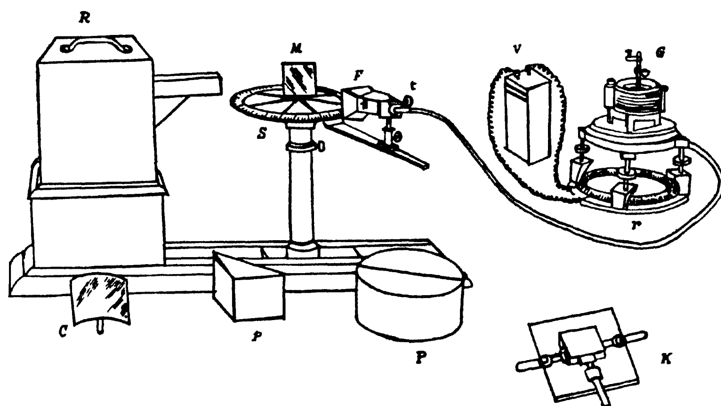


FIG. 10.12. Electric Radiator designed and used by J. C. Bose. *R*, radiator; *S*, spectrometer; *M*, plane mirror; *F*, funnel; *C*, cylindrical mirror; *p*, total reflecting prism; *P*, semi-cylinders; *t*, tangent screw by which the receiver is rotated; *v*, voltaic cell; *r*, circular rheostat; *G*, galvanometer; and *K*, crystal holder. (Reproduced from Bose (J. C.), fig. 17, p. 87.)

Crystals' appeared in the May 1895 issue of the *Journal of the Asiatic Society of Bengal.* Bose also determined the refractive indices of many substances. Further, he studied the influence of the thickness of the air-gap between

[a] Bose (D. M.) (2), pp. 7–21.

two dielectric slabs, on total reflection. Yet another investigation of his related to the study of the rotation of the plane of polarization. He demonstrated that a bundle of twisted jute fibres registered right- or left-handed rotation depending upon the right- or left-handed twist of the fibres.

Bose had a remarkable originality in the design and fabrication of apparatus. In 1897 when he was invited to deliver a lecture at the Royal Institution in London, he took with him an apparatus—similar to a micro-wave spectrometer with transmitter and receiver—constructed by himself at Calcutta. In an ingenious way he also constructed models in which mechanical or light stimuli could produce electrical responses. In 1900 he read a paper, 'On the Similarity in Responses in Inorganic and Living Matter', at the International Congress in Physics at Paris and later at the British Association for Advancement of Science at Bradford. His observations were met with criticism, and in order to convince his critics, Bose worked for two years in the Davy-Faraday Laboratory of the Royal Institution. He published eight papers during this period and completed a monograph: *Response in the Living and Non-living.*

The investigations of Bose showed that not only animal but also vegetable tissues under different kinds of stimuli (mechanical, application of heat, electric shock, chemicals and drugs) produce similar electric responses. He also proceeded to show that similar electric response to stimulation could be noticed in certain inorganic systems.

It is well known that Jagadish Chandra Bose later took up investigations on the phenomena of response-behaviour in plants, particularly *Mimosa pudica*, *Biophytum sensitivum* and *Desmodium gyrans* (Indian Telegraph plant). In 1907 his book *Comparative Electrophysiology* appeared. In all his investigations Bose displayed a new spirit and tried to offer original interpretations. He even attempted to devise models which were illustrative of the physical basis of memory. In recognition of his outstanding work, Bose was elected a Fellow of the Royal Society in 1920.

Bose retired as Senior Professor of Physics in 1915 but continued to be associated with the Presidency College as Emeritus Professor for about two years. In the meantime he raised money from the public for the establishment of a research institution. The new institute (called Bose Institute) came into being in November 1917 just north of his house on the Acharya Prafulla Chandra Road (formerly Upper Circular Road) in Calcutta. He nurtured this institution as its life Director till his death in November 1937. In his dedicatory address at the inaugural ceremony of the Institute, Bose observed: 'The advancement of science is the principal object of the Institute, and also the diffusion of knowledge. The investigations to be carried out in the Institute are for the further and fuller investigations of the many and ever opening problems of the nascent science which includes both Life and Non-life.'

'I have sought to associate the advancement of knowledge with the widest possible civic and public diffusion of it.' He then expressed to

desire 'that so far as the limited accommodation permits, the facilities of the Institute should be available to workers from all countries. In this

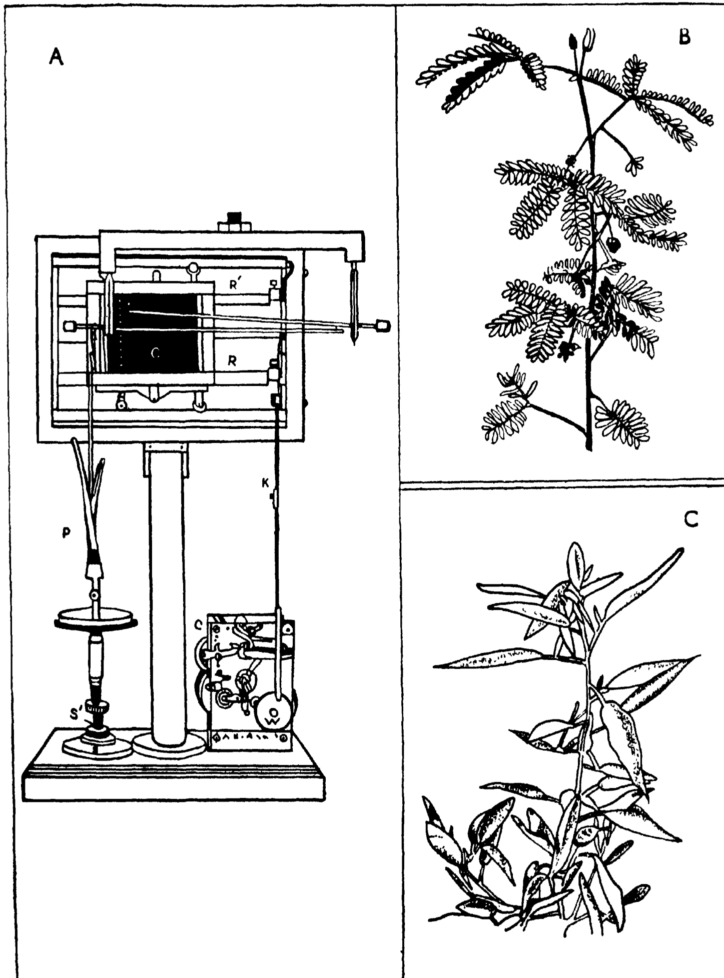


FIG. 10.13. (A) The High Magnification Crescograph designed by J. C. Bose; (B) *Mimosa pudica*; and (C) Desmodium plant. (Reproduced from Bose (D. M.) (1), pp. 22 and 16–17 respectively.)

I am attempting to carry out the traditions of my country which, so far back as 25 centuries ago, welcomed all scholars from different parts of the world within the precincts of the ancient seats of learning at Nalanda and Taxila'.[a]

[a] Bose (D. M.) (1), p. 28.

Prafulla Chandra Râу

In chemistry,[a] Prafulla Chandra Râу (1861–1944)[b] conducted systematic chemcial analyses of a number of rare Indian minerals with the object of discovering in them some of the missing elements in Mendeleev's Periodic Table. The results, though inconclusive, were published in the *Memoirs of the Geological Survey of India* in 1900. In the course of his analytical investigations, P. C. Râу noticed the formation of mercurous nitrate, a compound which was not known then. In 1896 he communicated a preliminary note on this to the *Journal of the Royal Asiatic Society*.

P. C. Râу's abiding interest in chemistry can be traced to the influence of extremely stimulating lectures of Alexander Pedler who was then Professor of Chemistry at the Presidency College. In his younger days, P. C. Râу saw in chemistry a great potential source for producing materials and resources for human benefit on a large scale. He was then 21. He appeared at a competitive examination and won the Gilchrist Prize which enabled him to go to Edinburgh for further studies.

In the University of Edinburgh P. C. Râу got the B.Sc. degree in 1885 and D.Sc. in 1887. The subject of his Doctorial dissertation was 'Conjugated Sulphates of the Copper-magnesium Group: A Study of Isomorphous Mixtures and Molecular Combinations'.

On his return to Calcutta in 1888, as it happened, P. C. Râу had to struggle hard for a suitable job for a year. During this period he received support and encouragement from Jagadish Chandra Bose. In 1889 he began his career as Assistant Professor of Chemistry in a temporary capacity in the Presidency College at Calcutta. He was an extremely inspiring teacher, lucid and lively in his exposition. P. C. Râу retired as Professor of Chemistry from the Presidency College after 27 years of service, and later became the Palit Professor of Chemistry at the newly founded University College of Science. It was largely owing to his efforts that the latter institution received the initial stimuli to become one of the centres of active chemical research in India.

P. C. Râу was a meticulous research worker. His researches at the Presidency College related to the isolation of mercurous nitrate, alkaline earths as well as methyl-ammonium and other alkyl ammonium nitrites. In the University College of Science he studied the compounds of metallic elements with organic sulphur derivatives, and examined the formation and behaviours of some of their simple derivatives. Under his guidance a number of students conducted researches on certain double sulphates, chemical and physical properties of compounds of zinc, cadmium, mercury, and so on. He thus became the founder of what has come to be known as the Indian Chemical School.

[a] Till the last decade of the nineteenth century, chemical investigations in India were of a sporadic type. For a brief account of this, see Chakravarti (R. N.), pp. 46–47.
[b] Râу (P.) (2), pp. 59–70.

Indian Association for the Cultivation of Science

In the last quarter of the nineteenth century the importance of science as the most fruitful intellectual activity, that it was in the West with its profound impact on economic and social life, was being increasingly realized by some of the enlightened Indians even. In evidence of this, it may be noted that the Indian Association for the Cultivation of Science was established by Dr. Mahendra Lal Sircar at Calcutta in 1876. Mahendra Lal was a remarkable man who had realized that science was the most powerful instrument of modern civilization. He had a brilliant academic record at the Calcutta Medical College, having won many a medal and distinction. His open-mindedness and aversion to dogmatic approach enabled him to advocate homoeopathic system also. A firm believer in the rationality of science, Mahendra Lal desired that the Indians should cultivate science on their own not only for their economic betterment but also for self-regeneration. In 1869 in the August issue of the *Calcutta Journal of Medicine*, he wrote an article on the need for a national institution for the cultivation of science by the natives of India. Sir Richard Temple, Lieutenant-Governor of Bengal, lent his support to his efforts. After six years of persuasive hard work and even against some opposition, he collected enough funds (a few lacs of rupees raised by prominent citizens of Calcutta and a donation of fifty thousand rupees by the Maharaja of Vizianagram) and ushered in the Indian Association for the Cultivation of Science on 15 July 1876.

In its initial stages the Association was intended to be a sort of a training school for the diffusion of scientific knowledge. In an eloquent address he said: 'For a variety of reasons the natives of India have long ceased to take an active part in the world of intellect... I would emphatically say that the Indian youth have shown as much aptitude for, and love of science, as the youth of any country in the world...' How true did his words reverberate! In the early decades of the present century, the Association attracted young research workers including the distinguished C. V. Raman. From its earlier phase as teaching institution in sciences, the Association began to encourage researches in the physical sciences. Raman, who later became Professor of Physics at the Calcutta University, was associated with this institution from 1907 to 1933. As a result of his researches at the laboratories of the Association, he won international recognition, was elected a Fellow of the Royal Society (1924) and awarded the Nobel Prize in Physics (1930) for his discovery of a new effect, now known as the *Raman effect*, in light scattering (appearance of additional lines in the spectrum of light scattered by a substance when illuminated by monochromatic light). Another eminent physicist K. S. Krishnan, also worked there and became the first Mahendra Lal Sircar Professor in 1933. The Professorship was created out of a donation of over a lac of rupees from Rai Bahadur Behari Lal Mitra, a wealthy citizen of Calcutta. In the history of development of modern science in India, the foundation of the

Indian Association for the Cultivation of Science is an important landmark; for it heralded the dawn of a national effort for the promotion of scientific movement in the country and an involvement of enlightened citizens.

STATE OF INDUSTRY

While the participation of Indians in the modern scientific investigations was clearly noticeable towards the close of the nineteenth century, the industry in India presented a sharp contrast. Perhaps a brief reference to the state of industry in India during the nineteenth century may not be out of place here.[a] In the west there was a constant interaction between science-based technology and industry at that time. New industries sprang up spectacularly as a result of the applications of science in the leading western countries. But in India there was practically no industrial base in the modern sense even in the first half of the nineteenth century. The East India Company thought it prudent to adopt a policy of complete *Laissez faire* in the field of industry. In its own interest in the cotton textiles, the Company even adopted a negative attitude which is too well known to merit special mention in this short account.

It may be noted here that as early as the seventeenth century A.D. India enjoyed a leading position in respect of its manufactures including superfine textile fabrics, indigo and saltpetre. Gujarat, Coromandel Coast and the Indo-Gangetic region were important regions of production. Surat, Musalipatam and Hoogly were the noted ports for export of high quality goods. However, the commerce in textile products began to show signs of decay by the end of the eighteenth century and almost went into oblivion by the middle of the nineteenth century.

Indigo

In respect of indigo there was a favourable factor, though it was prone to be short-lived. The decline of the indigo industry in the West Indies at that time acted as a powerful incentive to cultivate indigo on a large scale in India. The East India Company brought planters from the West Indies, while the required capital was raised from the savings of the Company's public servants. The result was that there was a phenomenal growth of indigo-processing factories in Bengal and Bihar by the end of the eighteenth century. In the first half of the nineteenth century Bihar, Banaras and the Doab regions emerged as the principal producers of indigo. But the industry had to see its end towards the close of the nineteenth century as a result of the discovery of the synthetic dye (1856) in England.

Jute and Cotton

The jute industry, from its beginnings in 1855 in Serampore (Bengal), began to flourish rapidly. In less than 50 years there were some 20 mills

[a] The following account is based on the publications of Mehta and Thomas as well as the official reports of the industries concerned.

owned by the British capitalists with 100,000 looms and over two lakh spindles for producing jute goods. When the traditional handloom industry of cotton fabrics fell a foul prey to the British Government's tariff policies, the Indian capitalists, particularly the Parsees, embarked upon the modern cotton industry. The first cotton mill was established in Bombay in 1853 with about 25,000 spindles; later another was established at Ahmedabad. Within a decade, Bombay and Ahmedabad became industrial centres for cotton fabrics (10 in Bombay and 3 in Ahmedabad). In 1890 there were as many as 137 mills which mostly produced cotton yarn for export to China and Japan. But soon Japan began to compete with India and captured the Chinese market.

Iron and Steel

The iron and steel industry was indeed in distress. This important industry proved a failure practically during the whole of the nineteenth century despite the concerted efforts made in this direction. In the Salem region[a] (Madras Presidency) one such effort was made in 1825 by Josaiah Marshall Heath, an erstwhile civil servant of the East India Company. He resigned from the lucrative job, raised loan from a British firm in Calcutta and spent four years in England to get the technical information, machinery and a few workmen. By 1830 he had erected the iron-smelting works at Porto Novo—two large and two small furnaces—for conversion of high grade iron ore (72% iron) into iron, using charcoal of good quality. Heath had planned to produce 400 tons of bar iron annually. The quality of the bar iron so produced received approbation even in England. In the meantime he had exhausted his resources and applied for government assistance to the tune of a lac of rupees as well as grant of exclusive rights for 25 years. Heath got both; and the rights granted to him were in fact similar to the Parliamentary privileges granted to Messrs. Boulton and Watt of England. But in the iron-smelting process using charcoal as the reducing agent he experienced difficulties, running as many as twelve unsuccessful trials. Again he was in financial trouble; and the Porto Novo works virtually came to an end by the middle of the nineteenth century.

In Bengal, an ironworks was started at Barakar by a private firm in 1839, and another near Ranigunj in 1855. Both of them met with failure. In 1875 the Bengal Iron Company came into being and, within two years of its erection, it began to produce pig iron at Rs.40 per ton as against the English pig iron at Rs.60 per ton. But the technological innovations, which were taking place in England then, enabled England to sell the pig iron at Rs.29 per ton in the very next year. This struck a serious blow to the Indian works. In 1882 the government took over the works and appointed one Ritter Von Schwarz,[b] an Austrian, who had a good deal of experience in mining and iron-smelting operations, to examine the works

[a] *Public Consultations*, 1833.

[b] *Fin. Deptt.*, Aug. 1882.

and submit new proposals. Schwarz prepared a detailed report including the plans of operation for about 25,000 tons of finished iron per year. The Bengal Iron Company was sold by the government to a private firm in 1889 when it was named the Bengal Iron & Steel Company. This Company was producing about 40,000 tons of iron by 1900; it was not producing any steel.

Coal and others

Coal-mining, from its small beginnings in 1820, progressed rapidly, particularly in the last decade of the nineteenth century, to meet the increasing demands of the jute and cotton industries, and the railways. Among the other industries may be mentioned the tanning industry (flourishing in Madras, Kanpur and Bombay), paper production (in Bengal, Lucknow and Poona) and a chemical works (in Calcutta). The last, known as the Bengal Chemical Works, was started in 1900 by Prafulla Chandra Rây who pooled all his resources to establish this industry which gradually rose to be one of the important chemical manufacturing concerns. But India was still without industries for producing sulphuric acid, alkalis and other heavy chemicals. These made their appearance only in the twentieth century.

CONCLUDING REMARKS

While considering the implantation of modern science in India in the eighteenth and the nineteenth centuries, a historically important context should not go unnoticed. Towards the close of the eighteenth century, and practically the whole of the nineteenth century, it was not Britain but France and later Germany which led the way in measures for the promotion of scientific and technological activities then. It is true that Britain ushered in the Industrial Revolution in the middle of the eighteenth century with far-reaching effects. The industrial face of Britain became bright and gradually the tempo of industrial production increased. The new production units and the townships which grew around them attracted into their fold the craftsmen as well as amateurs in large numbers. New associations were founded at industrial centres, such as Liverpool, Sheffield and Yorkshire. Their numbers were astonishingly on the increase, 10 to 20 per decade, with the result there were over hundred such societies by the end of the nineteenth century covering practically all the important towns. The new organizations enabled the scientists and technicians to think and work together irrespective of their social positions. More significantly, some of them played a substantial role in the ramification of scientific education by establishing new universities in their respective localities.

Apart from these organizations, there also sprang up what were known as mechanics' institutes.[a] In 1823 London and Glasgow had each a

[a] Cardwell, pp. 27–81.

mechanics' institute and in 1825, Birmingham. But within a few years, there were as many as 600 such institutes which catered to more than a hundred thousand apprentices. Practically every town, large or small, had its own mechanics' institute. Nevertheless, these organizations did not appear to have in them the necessary potential which could stimulate a vigorous growth of modern science in Britain. Illiteracy of the craftsmen and apprentices, inadequate financial support, and imbalances in management eventually led to the failure of the mechanics' institutes. Even within a decade of their establishment the institutes could not attract mechanics and artisans in sufficient numbers for purposes of training.

While the new organizations were showing signs of withering away, the established organizations of repute, like the Royal Society and the Royal Institution, seemed to be in no better shape. In the nineteenth century it was becoming increasingly apparent that scientific pursuits in Britain were on the decline and the State was in no mood to offer the much needed support. Humphry Davy even thought of writing on the decline of British science, but died before he could complete it. In 1830 Charles Babbage, Professor of Mathematics at the Cambridge University, wrote in his *Reflections on the Decline of Science in England* that the English people were rather indifferent to science and its intellectual possibilities, and considered the profession of law more attractive than scientific pursuits. He made a vigorous plea for the promotion of science in Britain at a national level.

In 1831 the Yorkshire Literary and Philosophical Society called a meeting of the 'Friends of Science' where the British Association for the Advancement of Science took its birth. The aim of the new organization was, as stated under its objectives, 'to give a stronger impulse and more systematic direction to scientific enquiry, to obtain a greater degree of national attention to the objects of science as well as a removal of those disadvantages which impede its progress, and to promote the intercourse of the cultivators of science with one another and with foreign philosophers'.[a]

Further, the scientific and technical education did not register substantial progress in Britain even in the nineteenth century. The universities seemed to be reluctant to offer specialized courses in sciences. In 1832 Baden Powell was still exhorting the Oxford University authorities to pay more attention to scientific studies. The Cambridge University gave encouragement more to mathematical studies than to experimental sciences. The London University (the model of the first three Indian universities) was no doubt of liberal disposition. Yet in 1858 it was still examining the desirability or otherwise of offering specialized science degrees.

The foregoing historical factors are of considerable importance to the understanding of the impact of modern science and technology on India, especially in the nineteenth century, in view of India's direct political, economical and educational contacts with Britain, and the policies pursued

[a] Mason, pp. 358–60.

by the latter from time to time in these fields. All the same, it is indeed refreshing to note that India showed indications of having received a substantial impact of western science by the end of the nineteenth century.

The first two decades of the twentieth century, which inherited the impact of the western science, witnessed newer efforts in the direction of providing a sound base for modern scientific teaching as well as research in India. The role of Governor-General Curzon needs special mention in this respect. His Educational Code and the Universities Act of 1904 heralded the dawn of unitary and centralized system of education. The universities, which were hitherto only the affiliating bodies, not only instituted regular inspection of colleges which were affiliated to them but also transformed themselves into teaching institutions. The Act declared 'that the universities to be incorporated for the purpose (among others) of making provision for the instruction of students, with powers to appoint university professors and lecturers, to hold and manage educational endowments, to erect, equip and maintain university laboratories and museums, to make regulations relating to the residence and conduct of students, and to do all acts, consistent with the incorporation of this Act, which tend to the promotion of study and research'. Immediately after the passing of the Act, it is significant to note that the Government of India made a recurring grant of five lacs of rupees per annum for a period of five years for the improvement of the university and collegiate education. Curzon believed not only in the education of the many but also in the co-ordination of the technical education with the industrial development. He even visualized that qualified Indian engineers and technical men would in time replace the Europeans in the Indian industry.

In 1902 the Board of Scientific Advice was established with a view to co-ordinating the scientific work which was carried out by official agencies. The reports of the Board used to be communicated through the Secretary of State for India to the Royal Society of London, for advice, though later this effort proved ineffective. The Imperial Agricultural Research Institute, as stated before, was started in 1903, and the Forest Research Institution at Dehra Dun in 1906. In 1911 the Indian Research Fund Association was founded by the Government of India for medical research. In the same year came into being the Indian Institute of Science at Bangalore (through the munificence of J. N. Tata) for advanced scientific research. In addition, several specialized scientific societies were in the offing at this time.

As the multitude of scientific institutions was spread over different parts of the vast country, the need arose, as early as 1913, for a periodic congressional gathering of scientific workers for exchange of information and stimulation of research activities. Thus in January 1914 the first session of the Indian Science Congress Association was held under the Presidentship of Asutosh Mookerjee at Calcutta in the premises of the Royal Asiatic Society of Bengal. Thirty-five scientific papers were discussed in six sections (Chemistry, Physics, Geology, Zoology, Botany and Ethnology), and over hundred scientists from different parts of the country were present

at this meeting for the first time. In his Presidential Address Asutosh Mookerjee emphasized: 'Personal association amongst scientific men is pregnant with important consequences, not merely by a fruitful exchange of ideas. The cultivators of science, by periodical meetings and discussions, may bring their aims and views prominently into public notice, and may also, whenever necessary, press them upon the attention of the government, a contingency by no means remote; for, as experience has shown, even the most enlightened governments occasionally require to be reminded of the full extent of the paramount claims of science upon the public funds.'

On his part, Asutosh Mookerjee played an effective role in making the Calcutta University the first institution to start postgraduate teaching and research in 1916. As a result of his efforts, some leading wealthy men of Bengal came forward with large endowments for this purpose. By 1919 the Calcutta University had postgraduate classes in physics and applied physics, chemistry, applied mathematics and experimental physiology. Undoubtedly, in the beginning of this century the modern science entered on a new stage in India and began to grow rapidly in the succeeding years.

11 RÉSUMÉ

B. V. SUBBARAYAPPA

IN the preceding chapters a concise account has been given of the various branches of science as they developed in India in the ancient and medieval periods, and also of the growth of western science in India up to the end of the nineteenth century A.D. The treatment has been subjectwise, and each subject has been dealt with in a broad chronological setting.

In this résumé an attempt has been made to highlight some important aspects and achievements of Indian science in the pre- and protohistoric, Vedic and post-Vedic periods, the Classical Age and after up to *c.* A.D. 1200, the medieval and the modern periods. Chapter and page numbers are given in bold and ordinary types respectively in brackets, wherever necessary, to indicate the portions or sections to be referred to for further details. A chronological chart depicting the major scientific and technological texts and developments up to the end of the nineteenth century A.D. is also appended.

THE great subcontinent of Asia, which in area is nearly equal to that of Europe with the exception of Russia and which goes under the name of *Bhāratavarṣa*[a] or India,[b] has played a distinct role in the history of technology and science. Geologically it is believed that during the Mesozoic era (about 230 million years ago) a great part of the now known Himalayan region was beneath the sea (called the Tethys sea), while the peninsula, possibly with the exception of the coastal area, must have been a land at least since the Permo-Carboniferous period (over 300 million years ago). The gradual uplift of the Himalayas is supposed to have occurred mainly in Eocene-Oligocene (about 30 to 40 million years ago), and the final phase of the mountain elevation in the Pleistocene periods. The principal features

[a] Though named after Bharata, a legendary monarch of the Lunar line, according to the *Viṣṇu Purāṇa*, the country belonging to the north of the ocean and to the south of the snowy mountains is called *Bhāratavarṣa*—a geographical definition.

[b] This word is derived through the Greeks from the Persicized form of the Sanskrit term *Sindhu* (the river).

of this subcontinent had assumed more or less the present shape and topography possibly by the early Pleistocene time (about one to two million years ago), save, in front of the newly elevated mountain ranges, the region which formed almost a longitudinal depression or a foredeep corresponding to the high mountainous terrain. It has been conjectured that this depression got filled up by alluvial and wind-blown deposits, and became the plains fit enough for habitation geologically not very long ago.[a] Known as the Indo-Gangetic plains because of flow of many a river belonging to the Indus-Ganges system, the plains are reputed for their fertility and effective manoeuvrability for agricultural operations, and have been the home, from time to time, of a number of different groups of people who developed their agriculture, arts, crafts and industries. There has been yet another fertile alluvial tract covering the region of modern Gujarat and Kathiawar formed by the river and estuarine depositions, which also witnessed the growth of advanced human settlements. In contradistinction to these alluvial formations which geologically are not old enough, is the much older laterite rocky terrain of the peninsula comparatively less fertile than the northern plains, and here also is found evidence of early human inhabitants some of whom belonged to the neolithic and chalcolithic stages. It should be noted that the natural environments provided by these geological features of the subcontinent and not inconsiderably the latter's geographical position with reference to the other culture-areas of the then known world have been not only stimulative to, but also determinative of, the endeavours of man the maker and man the thinker in this part of the globe.

As to the early man who wandered on this subcontinent there is little or no information, for no skeletal remains of the palaeolithic man have been unearthed so far in this region. Anthropologists believe that the terrain now known as the Siwaliks (a later phase of the Himalayan elevation) might have been the home of early man in India. In any case, in this area have been discovered some stone-tools which indicate a chopper-chopping tool culture in existence there perhaps over 150,000 years ago. That the early human had been active and groups of men existed in different parts of the subcontinent have been evidenced by some types of stone-tools found in the Punjab, Peninsular India, Kashmir, Bengal, etc. The Middle Palaeolithic Age in India corresponds to *c.* 25000 B.C. and the Late Stone Age to *c.* 5000 B.C. The neolithic culture which is characterized by some kind of habitation and agricultural practices leading to production of food has been noticed in the regions of Andhra, Karnatak and Kashmir even as late as *c.* 2000 B.C., while in some other parts of India like Rajaputana, Central India, the Deccan, etc., the chalcolithic culture has also been found in the period 1800 B.C.[b] However, earlier still in the region covering Sind, the Punjab, Rajaputana, Saurashtra and Baluchistan, there flourished a civilization (*c.* 2300–1750 B.C.) which was by far the largest of the world's three most ancient civilizations, covering an area of roughly 840,000 square miles.

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[a] Majumdar (R. C.), I, p. 82.

[b] Sankalia (4), pp. xxi–xxii.

The fact worthy of note is that in this subcontinent different culture manifestations have occurred in different periods and in different parts of the land, not always in the recognized sequence.

PRE- AND PROTOHISTORIC PERIOD

The neolithic man in India, apart from his primitive attempts at agriculture of which we have but scanty information,[a] was quite familiar with certain plants and animals which were part of his environment. His practical knowledge of animals has been handed over to us in the form of what are called 'haematite drawings' in the caves or sheltered rocks. Such drawings have been found on the rocky walls of the Vindhya hills in Mirzapur district (depicting hunters attacking a rhinoceros with barbed spears), in the caves of Hoshangabad district (portraying a giraffe), of the Kaimur hills (showing stag-hunts), and at Singanpur (representing an animal resembling a kangaroo, also horse and deer). It would seem that rhinoceros was then more widely distributed in India than at present. The neolithic potter was able to produce earthen vessels (generally globular with round bases and flair slips) which were hand-made, the potter's wheel obviously being unknown to him in the initial stages, as evidenced by the finds in the prehistoric rock shelters of Mirzapur, Laghnaj, Nagarjunakonda, Birbanpur, Burzahom and certain sites in the southern Deccan. Later he was able to devise the wheel and produce the wheel-thrown pottery, the specimens of which have been found in some of the neolithic settlements in south India.

The Harappan Culture

In India the history of technology and science begins naturally with the Indus valley civilization which is often referred to as the Harappan Culture, Harappa along with Mohenjo-daro being the important sites of archaeological value in the Indus valley. The Harappan culture had established commercial links with the neighbouring cultures in the central and western Asian regions. It is interesting to note that some Harappan seals have been found in the Lower Mesopotamia. There seemed to be brisk commercial relations between the Harappan culture and that of Mesopotamia at the time when the former was in a flourishing state. The archaeological evidence at Lothal indicates that there was sea-borne trade too. Some of the ceramic appearances, seals, amulets and ornamental forms found in the Harappan settlements, on closer analysis, are noticed to have their parallels in the Mesopotamian cultures. Even the religious belief like the worship of the Mother-goddess representing a fertility cult which was in vogue in the Harappan urban civilization was more or less similar to that practised in the early Sumerian village-cultures. Not a few of the animal motifs

[a] Archaeological evidence indicates the use of rice (*Oryza sativa* L.) and wheat (*Triticum vulgare-compactum*) in the chalcolithic sites of Navdatoli and Maheswar.

found on the Harappan seals are in common with those of Syria and Crete.[a] There is no denying the fact that there was a movement of ideas and techniques among the diverse culture-areas in the third and the second millennium B.C., and that the Harappan culture lay on the periphery of the already well-established central and western Asian cultures.

Be that as it may, the Harappan culture displayed certain original characteristics and underwent its own civilizational experiences. The overall picture of this culture appears to be that it had a reasonable agricultural surplus and a farming economy, developed a way of settled life and material culture enriched by many a craft and industry. The craft of potting had registered a technological progress. The Harappan pottery was mainly wheel-made, turned in various shapes and sizes out of the well-levigated alluvium of the Indus. The unearthed pottery specimens with a number of designs and colour combinations throw light on the fact that the production technique was standardized to a high degree. The Harappan potters also knew the art of glazing and it would appear that the glazed pottery found at Mohenjo-daro was probably the earliest specimen of its type. Metalsmiths were well versed in the techniques of making beads, sheet-making, rivetting, coiling and casting. The bronze figurine discovered at Mohenjo-daro was probably cast by the *cire-perdue* process. A number of metallic tools, mostly of copper and bronze, found in this area reveal that the Harappan metalsmiths had sound knowledge of cold-working and annealing of the metal. Of the tools, a special word needs to be said about a true saw which has the teeth and the adjoining part of the blade set alternatively from side to side, for a similar type of saw was unknown elsewhere until Roman times (5, pp. 275–83). Apart from metal-working, the Harappans knew the use of a number of minerals for ornamental, cosmetic and medicinal purposes. They had developed social sanitation and public hygiene to a high level as borne out by the town-planning, paved streets, water-supply, public baths and hydropathic establishments, discharge and drainage systems, etc., in their urban living. They also knew spinning and weaving and were well known for the burnt-brick-and-mortar constructions. Doubtless they had evolved a system of measurement and computational techniques which were necessary for not only constructions but also commercial transactions.

The animal representations on the Harappan pottery, seals, figurines and toys give an insight into their familiarity with and domestication of animals. Some 92 species of animals have been identified and of them mammals (41), molluscs, marine and land forms (31), reptiles (12), fishes (5) and birds (2) are notable. The domestic animals included the humped cattle, buffalo, ass, sheep, goat, elephant, camel, pig, dog and cat. The wild life comprised, among others, elephant, tiger, rhinoceros, wolf, jackal and chital, but no lion. A large number of seals depict a curious legendary animal called the unicorn, a male beast with one horn, a heavily built body of an

[a] Mode, pp. 1–12.

antelope or an ox with a long tuffed tail. The widely used domestic animal was the bull, and although the figure of cow is not represented on any of the seals, it was an important domestic animal (**8**, pp. 404–16).

The Harappans had attained a reasonably good level of agricultural practices; yet the plough was not in use. Likewise, of the metals, iron was unknown to the people of the Indus valley; and of the animals, horse was probably not in use then. The plough, iron and the horse of a superior breed began to be used in India by a new set of people of a new social order, whose thoughts and practices have come down to us in the form of several literary compositions known as the *Vedas*, *Brāhmaṇas*, *Āraṇyakas* and the *Upaniṣads*.

VEDIC PERIOD

This new set of people, sometimes referred to as the Aryans, made notable contributions to the development of science and technology in India, and from about the fifteenth century B.C. to about the eleventh or twelfth century A.D., the history of science in India is, by and large, that of their thoughts and religious practices, of their arts and crafts which took into their fold not a few of the locally existing thoughts and techniques which they encountered, reshaped and assimilated.

Ṛta

Of the principal Vedic thoughts which are of relevance to us, mention should be made of the natural law (*ṛta*) which finds adequate expression in the *Ṛgveda*. The Vedic seers conceived of this law as the real governing force of the universe and even the Vedic gods are considered to be either under the operation of this law or its guardians. The natural phenomena like the flow of rivers, occurrence of night and dawn, are explained in terms of this natural law. It is now known that there was among the Babylonians[a] a conception of natural law with reference to divinity. Among the Greek thinkers, Heraclitus (*c.* sixth century B.C.), Democritus (*c.* fifth century B.C.), Plato (427–347 B.C.) and Aristotle (384–322 B.C.) are known to have given expression to the idea of natural law. A fact of great significance is that the importance given to and the role of *ṛta* in the movements governing the human world and the cosmic universe alike, as depicted in the *Ṛgveda* and the later Vedic literature, point out that the Vedic people had an instinctive conviction in the natural order—a conviction which is of prime importance for sustenance of scientific attitude (**9**, pp. 453–55).

Pañcabhūtas

Another doctrine which gradually took shape out of certain speculative layers of the Ṛgvedic thought and the early *Upaniṣads* is the one concerning

[a] Needham, II, pp. 533 ff.

the *pañcabhūtas*. Wholistic in nature, the fivefold character of the *pañcabhūtas*, viz. *pṛthvī*, *ap*, *tejas*, *vāyu* and *ākāśa*, aimed at a coherent explanation of the apparently unordered and seemingly diverse world of matter, qualities and motion. It was tacitly assumed that the five *bhūtas* to which belonged all the subtle and the gross, the perceptibles and the imperceptibles, and the limited and the unlimited, provided a base for rational interpretation of the problem of matter. With such wide application, the doctrine of the *pañcabhūtas* was able, as no other could, to permeate practically all the departments of Indian thinking and to become, as it did, an integrated component of the major philosophical systems. The *Sāṃkhya*, *Nyāya* and the *Vaiśeṣika* have laid a special emphasis on the *pañcabhūtas*, while the Jaina, Bauddha and Cārvāka recognize the first four *bhūtas*. Special mention should be made of the *Sāṃkhya* which in addition enumerates the five *tanmātras* or the subtile states corresponding to the five *bhūtas*. Perhaps the *tanmātras* were conceived so as to share the characteristics of both mind and matter. It is interesting to note that in the west the doctrine of five elements—earth, water, air, fire and ether—also played an important role in the Aristotelian interpretation of the universe and attracted the attention of thinkers in Europe as well as in West Asia for a long time. Nevertheless, the way in which the *pañcabhūta* doctrine became intertwined not only with the general inquiry into the intelligible reality but also with the notions concerning the human body merits special attention. It may be emphasized that the Indian classical medical texts are indeed one in describing the interplay of the five *bhūtas* in the organic as well as inorganic world. Human body is regarded as a combination of the *bhūtas* and of soul. In the *Suśruta Saṃhitā* there is an integrated exposition of the way in which the five *bhūtas* shape the human body from its very conception. The foodstuffs and other substances are classified in terms of the five *bhūtas*, as also the six *rasas* which, according to the classical medical texts, play an important role in the physiological processes. Such, then, was the viability of the doctrine of the *pañcabhūtas*, a proper understanding of which is absolutely essential for obtaining an insight into various facets of science in India (9, pp. 455–61).

Vedic Astronomy

In the *Ṛgveda* are found certain symbolic hymns and references which throw ample light on the astronomical ideas of the Vedic Indians. Keen observers as they indeed were, the Vedic priests possessed adequate knowledge of the course of the sun, the path and phases of the moon, the bright wandering objects or the planets, the starry firmament, occurrences of eclipses and the like. Their intuitive minds developed a thought-pattern concerning the motion of the astronomical bodies. The moon became the obvious choice for determining the month and, in fact, the moon was referred to as *māsakṛta* (maker of month) similar to the modern word, month, being derived from the word 'mooneth'. There were two systems of

reckoning—the *amānta* and the *pūrṇimānta*. The *Ṛgveda* refers to a number of *nakṣatras* (asterisms) as well as the course of the moon through them. The names of the lunar months were after those of the *nakṣatras* in which the full moon occurred. Known as 'lunar mansions', the *nakṣatra* system seems to be characteristically Indian. For, according to Max Müller, 'the Babylonian Zodiac was solar and, in spite of repeated researches, no trace of a lunar Zodiac has been found, where so many things have been found, in the cuneiform inscriptions. But supposing even that a lunar Zodiac has been discovered in Babylon, no one acquainted with the Vedic literature, and with the ancient Vedic ceremonial, would allow himself to be persuaded that the Hindus borrowed that simple division of the sky from the Babylonians'.[a] It must, however, be noted that there is some sort of an agreement[b] between the *nakṣatras* and the Chinese *hsius*, 28 in number, which were named after constellations with determinant stars. The Arabian *manazils*, again 28 in number, correspond, by and large, to the *nakṣatras*; and as many as 19 *manazils* are in agreement with the corresponding *nakṣatras*. But as a lunar Zodiac, the Chinese system appeared later (*c.* second century B.C.) and later still the Arabian *manazils*. The Indian *nakṣatras* are 27 or 28 in number[c] (the *Atharvaveda* mentions 28 *nakṣatras*) and in each *nakṣatra*, the brightest star is referred to as *yoga-tārā*—a star connected with the first point on the ecliptic of the division or near it, north or south, but always being capable of occultated by the moon or in conjunction with the moon or planets. In effect, the *yoga-tārās* furnished the Vedic priests with the necessary means of observation (**2**, pp. 66–72).

The priests whose reputation and survival in the Vedic society depended upon the performance of sacrificial rites at auspicious times had developed calendars which were luni-solar. In other words, they used the *nakṣatras* also to follow the motions of the sun, although they did not map the sky by the heliacal risings or settings of certain stars in the same way as the Babylonian or the Egyptian star-gazers did. Even so they were able to co-relate the motions of the moon and the sun in their own way. In course of time, a method of intercalation came into vogue and an additional month of 30 days (subsequently 25 or 26 days a month) was added at the end of a specific period, normally five years, for luni-solar adjustments. The length of the five-year period ($5 \times 360 = 1{,}800$ days) was thus made up to 1,830, 1,825 or 1,826 (modern figure 1,826$\frac{1}{4}$ days) (**2**, pp. 75–76). The lunar day, *tithi*, is again peculiar to Indian astronomy. The lunar month was divided into two *pakṣas* of 15 *tithis* each. The 30 *tithis* of the lunar month were found to overrun the days of the actual lunar month of 27

[a] Max Müller, p. 126.

[b] Nine of the Indian *nakṣatras* agree with the corresponding *hsius* both in respect of the determinant stars and the number of stars associated with the constellations; for eleven *nakṣatras*, the determinants are different though they belong to the same constellations; for the remaining *nakṣatras* the determinants are selected from different constellations.

[c] To *Abhijit*, the 28th *nakṣatra* (determinant two lyrae), no *nakṣatra* space has been assigned in the ecliptic.

or 28 days. 'They were probably introduced merely to establish some sort of harmony between the revolutions of the sun and the moon, and to help trace the path of the moon through the *nakṣatras*. But since the apparent velocity of the moon (and hence the lunar day) is not uniform, the *tithis* were purely spatial abstractions.'[a]

Another important aspect of the Vedic astronomy is the concept of a cosmic cycle associated with the cosmic creative spirit. According to the *Śatapatha Brāhmaṇa*, Prajāpati's year consists of 10,800 moments. It would seem that this figure was derived from the 12 months, 30 nychthemera of each month and 30 moments of each nychthemeran (i.e. $12 \times 30 \times 30 = 10{,}800$). The *Ṛgveda* has 10,800 metrical divisions of 40 syllables each, thus giving a figure of 432,000 ($10{,}800 \times 40$) syllables. This figure of 432,000 gave rise to an important astronomical period in the Siddhāntic astronomy later in India, in terms of a *mahāyuga* of 12,000 divine year being equivalent to 360 solar years ($12{,}000 \times 360 = 4{,}320{,}000$ years). It is interesting to note that in about the fifth century B.C. Heraclitus alluded to a Great Year of 10,800 years and Berossos, the Babylonian astronomer, spoke of a cosmic cycle of 432,000 years. 'These figures first appeared in India long after the *Śatapatha Brāhmaṇa* was written, and although Greek and Babylonian astronomers were not otherwise greatly influenced by Indian ideas, they must have been in this respect.'[b]

Vedic Mathematics

The mathematical knowledge in the Vedic period seemed to be of a high order. That the numbers and their reckoning had a special appeal is clear from the fact that the *Yajurveda* has names of numbers even up to 10^{12} and the *Pañcaviṃśa Brāhmaṇa* gives an account of numbers in ascending decimal scale. It is interesting to note that the highest terminology of the Greeks (which probably came into use by about the fourth century B.C.) was *myriad* (10^4) and of the Romans was *mille* which denoted just a thousand (10^3) only. It may be added that in some of the later Jaina and the Bauddha literature is found terminology to express numbers as large as 10^{29} and 10^{53} (3, pp. 140–41).

A proper scientific vocabulary of number names was also developed so as to be permissive of operations including addition, subtraction and multiplication. Fundamental arithmetical operations involving elementary fractions were also known, as evidenced by the occurrence of such names, as *ardha* ($\frac{1}{2}$), *tripāda* ($\frac{3}{4}$) in the *Ṛgveda*, and *pāda* ($\frac{1}{4}$), *śapha* ($\frac{1}{8}$), *kuṣṭha* ($\frac{1}{12}$) and *kalā* ($\frac{1}{16}$) in the *Maitrāyaṇī Saṃhitā*. *Aṃśa* and *bhāga* denoting fractions in general occur in the *Śulba-sūtras* (3, pp. 143–44). In the field of geometry, the *Śulba-sūtras* (Rules of the Thread or Measuring Chord), which as part of the *Kalpa-sūtras* deal with sacrificial altar-constructions (*citi*) using a definite number of bricks of fixed dimensions, deserve special

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[a] Taton, p. 137.

[b] Taton, pp. 137–38.

attention. Of them, mention may be made of *Baudhāyana*, *Vādhula*, *Āpastamba*, *Hiraṇyakeśin*, *Mānava*, *Vārāha* and *Kātyāyana*. They deal with positions and spatial magnitudes with reference to the construction of geometrical forms on which the sacrificial fires had to be raised. The other geometrical notions found in them include the construction of squares and rectangles, relation of the diagonal to the sides, and equivalent rectangles and squares. Both *Āpastamba* and *Baudhāyana* describe a square equal to the sum of two different squares like $3^2+4^2 = 5^2$; $5^2+12^2 = 13^2$; $8^2+15^2 = 17^2$; $7^2+24^2 = 25^2$; $12^2+25^2 = 37^2$, etc. It is well known that according to the theorem attributed to Pythagoras (*c*. fifth century B.C.) 'the transverse chord of a rectangle produces (by the construction of) a square on itself, what the length and the breadth produce separately'. According to the *Śulba-sūtras* the diagonal of a rectangle produces by itself both (the areas) produced separately by its two sides. No wonder then some western scholars share the view that the origin of the Pythogorean theorem can be traced to the Indian *Śulba-sūtras*.

Another notable aspect of the Vedic mathematics is the way in which the values of such irrational numbers as $\surd 2$ and $\surd 3$ are given to a high degree of approximation, although the method by which these values are arrived at has not been indicated in the *śulba* texts. Yet another relates to permutations and combinations. The Vedic meters with syllables such as 6, 8, 9, 11, 12 and so on were formed by permutations and combinations of syllables by changing the long (*guru*) and short (*laghu*) sounds within each syllable group. The triangular array formed by the bionomial coefficients (referred to as Pascal's triangle which appeared in Europe not before the sixteenth century A.D.) was known in India in the form of *meruprastāra*, a pyramidal expansion of the number of combinations of 1, 2, etc., syllables formed of short and long sounds. This was dealt with later in a methodical way by Piṅgala (*c*. third century B.C.) in his *Chandaḥ-sūtra*, and was further extended to a binomial theorem $(a+b)^n$ by Halāyudha in the eleventh century A.D.[a]

Medical Knowledge

As to the medical knowledge of the Vedic Indians, the *saṃhitās* refer to a number of ailments affecting the head, eyes, ear, heart, lungs, stomach, skin, rheumatism, etc. Diseases are said to be caused by congenital factors, change of seasons and minute organisms in the body. There is, however, no attempt to classify the diseases based on some principle. No doubt the magical procedures, charms and imprecations, chanting of *mantras* and other rituals were part of the general treatment of diseases. But a large number of plant remedies were known and some minerals and animal products were also used as healing agents. The Vedic physiology was based upon the concept of *prāṇa* (breath) which was supposed to be the

[a] Bag, pp. 68–74.

sustainer of life. Nosology was, by and large, descriptive in approach and etiology was noted for its absence. The anatomical and physiological facts, though found considerable in the Vedic texts, appear to be without any rational classification. Nevertheless, the Vedic medical vocabulary speaks of their careful observation of the human body and its ailments, and these paved the way for codification of knowledge later as found in the *Āyurveda* which is regarded as a part (*upāṅga*) of the *Atharvaveda*.

Knowledge of Plants and Animals

There is ample literary evidence to show that the Vedic Indians possessed considerable knowledge of the morphology and internal structure of plants. And they were able to distinguish and name the different parts of plant—root, shoot, stem, leaves, twigs, flowers and fruits. They knew the difference between the *tvac* or *valkala* (skin) and the inner *sāra* (nutrient fluid). Plants were divided broadly into three groups—*vṛkṣa* (tree), *oṣadhi* (herb) and *vīrudh* (creeper). The *Atharvaveda* subdivides the herbs into seven types based on their morphological and other characteristics (7, pp. 376–78).

Of the animals, there are over 260 names used in the Vedic literature, denoting mammals, birds, some reptiles, fishes and insects. The *Atharvaveda* gives an account of 16 types of *kṛmis* which are poisonous and causative of diseases in cattle and man. The domestic animals included the cow, bull, buffalo, elephant, horse, sheep, goat, dog and cat. As to the wild animals, lion was known to the Vedic Indians.

P.G. Ware

In respect of the material culture and technological practices of the Vedic period, a special significance attaches to the advent of the Painted Grey ware and iron. The Indo-Aryans, according to some scholars, developed and used a *de luxe* type of pottery now christened by the archaeologists as the Painted Grey ware. It has been surmized that the Indo-Aryan settlers on the Indo-Gangetic plains possessed a knowledge of some similar ceramic used in parts of Iran, Sistan, etc. (*c.* second millennium B.C.), and, utilizing the locally existing ceramic techniques, they evolved the appropriate baking conditions for the production of the Painted Grey ware. This ware, first noticed at Ahicchatra and belonging to a date range of *c.* 1000–400 B.C., has, by and large, an extensive western distribution. A point worthy of note is that a number of iron objects have been discovered in association with the later phase of this ware in several excavated sites (5, pp. 285–87).

Iron

Though there are no details of the iron metallurgical practices in the Vedic literature, it is reasonable to suppose that the small furnaces employed for the extraction of iron might well have been of an open hearth

type. The word *ayas* used generally for the metals like copper or bronze began to acquire the connotation of iron as noticed in the later Vedic texts. On the basis of the archaeological evidence it seems to be fairly certain that iron was introduced into India by *c.* 1000–800 B.C. A charcoal sample from an early level of Atranjikhera II (where some iron objects were found) gives a radiocarbon date of 1025±110 B.C. At Hastinapur have been found a couple of slags of iron in the later levels of the Painted Grey ware horizon, indicating local iron-smelting operations as early as *c.* 1100–800 B.C. It may be mentioned that the earliest smelting operations of iron can be dated as far back as the second millennium B.C. in the region of Asia Minor and Caucasus, and there was by the end of the second millennium B.C. an appreciably large use of iron in the Near East whence the Indian iron metal-workers possibly derived their technical knowledge. But the fact of significance is that within the next five to six centuries of the advent of iron in India, the technical proficiency reached was so high that the Indian iron and steel objects earned the admiration of the western world (**5**, pp. 287–90).

Agriculture

In the Vedic period agriculture was an important vocation and not a few of the then social and religious customs were associated with the agricultural operations of ploughing, sowing, reaping and threshing. The plough, sickle, sieve and the contrivance for winnowing were among the agricultural implements. Of the important grains grown in this period, viz. wheat, rice and barley, significantly enough the *Ṛgveda* does not mention rice at all indicating that rice was a wild growth and not yet cultivated in the early period of the Indo-Aryan settlement. The *Yajurveda* and the *Atharvaveda* contain references to rice of different varieties as well as to several agricultural operations. The Vedic farmers are credited with the practice of improving the fertility of the soil by the method of rotation fallowing and this system appears to have been followed in the west at a later date, according to Roxburgh, the Father of Indian botany (**6**, pp. 352–54).

POST-VEDIC PERIOD

Āyurveda

In the post-Vedic period, the *Āyurveda* as a rational assemblage of methodical concepts and systematic therapeutic practices occupies an honoured position. Even though the celebrated classical texts of the *Āyurveda*, viz. the *Caraka* and *Suśruta Saṃhitās*, which have come down to us, took their present form probably in the early centuries of the Christian era, the thoughts and practices enshrined in them were doubtless in vogue from about the seventh or sixth century B.C. The prime object of the *Āyurveda* is the preservation of human life, of animals and even of plants. In man, life is the manifestation of body, senses and the spirit according to

Āyurveda. In its doctrinaire approach, this science of life owes a great deal to the philosophies of the *Sāṃkhya*, *Yoga* and the *Vaiśeṣika* adopting the *Vaiśeṣika* principles in so far as the *dravya-guṇa vijñāna*, the *tridoṣa* theory and the *saptadhātus* are concerned, and the *Sāṃkhya* principles relating to the *pañcabhautika* body and its evolution from *puruṣa-prakṛti.* As has been noticed, the *Āyurveda* believes that the world consisting of the inorganic as well as the organic (*sthāvarajaṅgamarūpa*) is formed out of the *pañcabhūtas.* The entire gamut of substances used for medicinal purposes are referred to, broadly, as *ākāśīyadravya*, *vāyavīyadravya*, *taijasadravya*, *āpyadravya* and *pārthivadravya*. The *Āyurveda* deals with the science of medicine in terms of eight divisions (*aṣṭāṅgas*), viz. *śalya* (surgery), *śālakya* (treatment of diseases of E.N.T.), *kāyacikitsā* (internal medicine), *bhūta-vidyā* (treatment of supernatural diseases), *kaumārabhṛtya* (paediatrics), *agada* (toxicology), *rasāyana* (rejuvenation) and *vājīkaraṇa* (virilification). Of the two most important classical texts of the *Āyurveda* (4, pp. 224-27), the *Caraka Saṃhitā* gives importance to internal medicine and the *Suśruta Saṃhitā* accords a special position to surgery.

Central to the diagnosis as well as treatment of diseases, according to the *Āyurveda*, is the doctrine of *tridoṣas*—*vāta*, *pitta* and *kapha*. They are referred to as *tridhātus* when they are in their normal states, supporting the bodily functions; and they become *tridoṣas* or vitiating agencies if they are deranged or in a state of imbalance. Though *rakta* (blood) is not included as the fourth factor or agency, the *Āyurveda* recognizes the role of *rakta* along with the *tridhātus* in the maintenance of the bodily functions. The *tridhātus* are recognized in terms of the five elements thus: *ākāśa*+*vāyu*→ *vāta*; *agni*→*pitta*; and *ap*+*pṛthvī*→*kapha*. The *tridoṣas* are believed to be all pervasive in the body, though certain areas as cardinal seats for each of them have been recognized. Each of the *tridoṣas* is thought of in terms of five functional aspects, *vāta*: *prāṇa* (governing respiration), *udāna* (for uttering sounds and speech), *samāna* (separation of digested juice), *vyāna* (carrying the bodily fluids) and *apāna* (expelling faeces, urine, etc.); *pitta*: *pācaka* (aiding digestion and imparting heat), *rañjaka* (imparting redness to the chyle so that it could become blood), *sādhaka* (increasing brain power), *alocaka* (aiding vision) and *bhrājaka* (improving complexion); and *kapha*: *kledaka* (moistening food), *avalambaka* (imparting energy and strength), *bodhaka* (tasting), *tarpaka* (governing the functions of eye and other sensory organs) and *śleṣmaka* (lubricating). The foregoing methodical conceptual scheme is a characteristic of the Indian system of medicine.

Of the other characteristic concepts of the *Āyurveda*, those concerning *rasa*, *guṇa*, *vīrya*, *vipāka* and *prabhāva* deserve special mention, for the *Āyurveda* holds that every substance, animal, vegetable or mineral, is a repository of these five attributes. *Rasas* are six in number (*madhura*, *amla*, *lavaṇa*, *kaṭu*, *tikta* and *kaṣāya*). There is a detailed account of the properties and effects of each of these *rasas* in the Āyurvedic classics, as the knowledge of the *rasas* is considered as essential for therapeutics. The term *guṇa* refers to *śārīrika guṇas*, twenty in number such as *guru*, *laghu*,

sāra, *sthira*, *sāndra* and *drava*. Substances are taken in for the growth as well as maintenance of the body in the context of these *guṇas*. *Vīrya* has been recognized generally as of two kinds, *uṣṇa* and *śīta*, and as causative of certain manifestations such as cheerfulness, strength, thirst, giddiness, etc. *Vipāka* may be understood as the biochemical processing of food, while *prabhāva* represents the over-all effect on the body and mind.

The theoretical basis for the way in which the food gets digested and assimilated into the body is again the doctrine of the *pañcabhūtas*. The agency which brings about the transformation of the food into the *rasas* is referred to as *jāṭharāgni* which means literally 'fire in the stomach', but connotes a wealth of meaning inclusive of all digestive processes in the stomach as well as in the intestines. The word *agni* is significant, for it actually cooks (*pāka*) and cooks specially (*vipāka*) the food for absorption by the bodily tissues. The chyle or *rasa*, in its sojourn in the body, gets transformed into *rakta* (blood), *māṃsa* (muscle), *medas* (fat), *asthi* (bone), *majjā* (marrow) and *śukra* (semen) in the order stated. The *rasa* and the aforesaid six are known as *saptadhātus* which maintain the body. At each stage of transformation, the causative agent is called *dhātvagni*. Each *dhātu* has three manifestations, viz. *sthūla* (gross), *sūkṣma* (fine) and *kiṭṭa* (refuse). The first is in the nature of the concerned *dhātu* and the second passes on potentially the character of the succeeding *dhātu*. According to the *Āyurveda* the principal seat of *rasa* is heart, and the fluid moves on through 24 tubular vessels called *dhamanīs*. Besides *dhamanīs*, there are also *śirās* (small vessels which do not pulsate) and *srotas* (minute vessels which lie in between smaller *dhamanīs* and *śirās*).

Treatment in *Āyurveda* is a two-way process: elimination of deleterious ingredients and replenishment with the harmonious ones, so that the *tridoṣas* become *tridhātus* again. All drugs, therapeutic procedures and even surgery are employed towards this end. Among the specific therapeutic measures are cleansing accumulated bodily wastes, internal as well as external medication; use of eye-drops and eye-salves; gurgles; fumigation of ear, nose and throat regions; liquid unguents, lotions, creams, oils, etc., for the skin; suppositories, tampons, soaked cotton swabs, etc., for the bodily openings; enemas and douches; various kinds of bath; fomentations; antisepsis by fumigation; hypertonic salt solutions for surgical dressings; astringents as styptics for bleeding wounds and abrasions, etc. (**4**, pp. 248-50). As to the drugs, the *Āyurveda* has an extensive materia medica. The *Caraka Saṃhitā* lists over 341 plant substances, 177 drugs of animal origin and 64 mineral compositions, while the *Suśruta Saṃhitā* contains over 395, 57 and 64 respectively (**4**, p. 251). Generally the plant products were preferred for both oral and non-oral medication, for it was believed that the organic plants were composed of the five *bhūtas* while the inorganic metals and minerals were supposed to consist of *pṛthvībhūta* only. In addition, the availability of a wide variety of medically efficacious plants in the environment was also responsible for such a preference. A practitioner in Āyurvedic medicine was expected to observe high standards of

ethics of the medical profession, such as self-control, courage, compassion, purity of mind and body and expert knowledge of the medical science. He was enjoined to prepare medical prescriptions from carefully selected raw materials under his own supervision (4, pp. 245–46). As a comprehensive medical science of all living creatures, the *Āyurveda* was concerned with the treatment of animals and plants too. There are special treatises dealing with the treatment of bovine animals (*gavāyurveda*), horses (*aśvavaidya*), elephants (*hastyāyurveda*) and plants (*vṛkśāyurveda*) (4, pp. 254–56). Besides, other standard works on the *Āyurveda*, some of the *purāṇas* and encyclopaedic works also contain sections of this type of medical procedures.

Surgery

Suśruta describes surgery (*śastrakarma*) under eight heads: *chedana* (incision), *bhedana* (excision), *lekhana* (scarification), *vedhana* (puncturing), *eṣaṇa* (exploration), *āharaṇa* (extraction), *visrāvaṇa* (evacuation) and *sīvana* (suturing). The surgical instruments described include 101 varieties of blunt instruments, and 20 kinds of sharp instruments, such as forceps, tongs, scalpels, catheters, bougies, trocar, syringes, speculums, needles, saws, scissors, lances, hooks and probes. A number of them resembled the mouths or beaks of birds, beasts or some other types of animals. Details are given of how they should be made from fine metal (steel or the *pañcaloha*), their dimensions, handles, etc. Cataract-crouching was an established surgical feat with which even the surgeons of ancient Greece and Egypt were not familiar. In the *Suśruta Saṃhitā* there is a vivid account of craniotomy and anal fistual operation bestowing careful attention on pre- and post-operative treatments. The Indian surgeons were aware of how the blood vessels should be ligated, and often used cautery. They laid stress on practical training to attain the much needed proficiency in surgery. Incisions were practised on fruits, scarification on stretched skins of deer, goat or sheep with the hair still on them, puncturing on distended bags, venesection on blood vessels of dead cattle or the hollow stalks of lotus plants, cauterization on meats, suturing on thick cloth and so on. The marrow of jackfruits and similar types of pulps and the teeth of dead animals provided the practising ground for extraction. The suturing material employed generally was made of flax, hemp and bark fibres. D. Guthrie rightly observes: 'It was in surgery above all that the ancient Hindus excelled. Suśruta described more than a hundred instruments. This was their greatest contribution to the art of healing and the work was bold and distinctive. It is not unlikely, though difficult to prove, that some of it was of Greek origin. Some, indeed, state that the Greek drew much of their knowledge from the Hindus.'[a] As Neuberger says: 'The outstanding feats of the ancient Indian surgery related to laparotomy, lithotomy and plastic operations.'[b] The *Suśruta Saṃhitā*

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[a] Guthrie, p. 19.

[b] Neuberger, pp. 57–58.

is regarded as the earliest document which gives a detailed account of rhinoplasty. Yet another feat related to the joining of the lips of wound by causing them to be bitten by ants and then cutting off the body of the ants, leaning behind the mandibles which would clamp the wound. The Arabs adopted this method later.[a]

Indian medical knowledge and surgical practices influenced in no small way those in Greece and Arabia. The Hippocratic treatise *On Breath* deals in much the same way with its pneumatic system as we find in the Indian concept of *vāyu* or *prāṇa*. Plato in his *Timaeos*, strangely enough, discusses pathology almost in the same manner as the doctrine of the *tridoṣa*. Filliozat says: 'India may very well have influenced the Hippocratic Collection and the *Timaeos* particularly, since Plato failed to mention his sources and since, moreover, his doctrine is closer to the Indian than to that of any contemporary Greek school. The influence of Indian ideas on certain aspects of Greek medicine during Plato's time is further supported by the mention of Indian medicaments, including pepper, in the *Diseases of Women*, part of Hippocratic collection. Indian medical knowledge must have seeped through the Parthian empire, then the overlord of parts of India and Greece alike along the trade routes described by Strabo and Pliny.'[b] Megasthenes described diseases of elephants and their remedies borrowed from the *Hastyāyurveda*. The Roman Celsus (*c.* first century A.D.) gave in his medical works a graphic account of lithotomy which was practised in India much earlier. Galen (A.D. 131–201) of Pergamum, who spent most of his life in Rome, makes no secret of his borrowing from the Indian sources the material relating to ointment for the eyes and the Indian plaster. It is well known that the Indian herbals were sought after in the Roman world.

Physical Concepts

While the *Āyurveda* had established itself as medical science *par excellence*, there were, during the post-Vedic period, certain systems of philosophical thought which were assuming a crystallized or aphoristic form. Of them, the Vaiśeṣika system deserves special mention. Supposed to have been propounded by a sage called Kaṇāda, Kaṇabhuj or Kaṇabhakṣa, the *Vaiśeṣika Sūtras* deal with a number of physical concepts encompassing substance, attributes, motion, space, time and atomism in a cryptic form. It so happened that these concepts set the tone as it were for the interpretations of the physical world by a number of exponents over a long period of time. The *Nyāya Sūtras*, the proto-layers of which could be found even in the fourth century B.C., supported the Vaiśeṣika views and, as could be expected, a syncretic Nyāya-Vaiśeṣika school came into being in course of time. The Indian philosophical systems are of great value from the point of view of the physical ideas which developed in India.

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[a] Taton, p. 157.

[b] Taton, p. 156.

N.B.P. Ware

A new type of ceramic known as the Northern Black-polished ware came on the scene (*c.* 600–500 B.C.), first in the region of modern Bihar and eastern Uttar Pradesh and in course of time spread to some of the other parts of northern, central and southern India. Made on a fast-spinning wheel using fine clay and fired to a high temperature in kilns under controlled conditions, this black-to-glossy-grey ceramic was reputed for its metallic sound. Its wide distribution and association with iron need special notice (5, pp. 294–98).

Glass

It would appear that in the first quarter of the first millennium B.C. the technique of production of glass objects like beads and bangles, mostly the former, was known in India. Yet it was perhaps from the sixth century B.C. onwards that the progress of glass technology became noticeable. At Taxila the Bhir Mound has yielded in the sixth-fourth century B.C. levels a number of glass beads of several shapes and colours. As one of the outposts of the north-western frontier of the Mauryan empire then, Taxila was prone to receive and assimilate foreign influences in the technique of glass production. That this was the case has been borne out by the glass objects found later at the new city of Sirkap at Taxila during first century B.C.-first century A.D. Production of glass objects was rather widespread inasmuch as a number of glass objects have been found in places like Ujjain, Nasik, Ahicchatra, Sravasti, Kolhapur, Kaundinya, Brahmagiri and Arikamedu to name a few out of some 30 sites known. The early Indian glass-makers were skilful in controlling the temperature of fusion, moulding, annealing, blotching and gold-foiling, the last being done in an exquisite manner (5, pp. 291–94).

Iron

In the post-Vedic period the knowledge of the use of iron in the form of a number of tools and implements was not only on the increase but also widespread. The use of bellows which made its debut during this period enabled the ironsmiths to produce a number of tools and implements on a large scale. Iron objects of different descriptions including bars, knives, hooks, sickles, arrowheads, hoes, rings, daggers, nails, choppers, etc., have been reported from a number of archaeological sites and the date-range of most of these finds is 600–200 B.C. The sharp iron implements were used with great effect in the clearance of jungles and expansion of settlements. The ploughshare tipped with iron enabled deep ploughing which resulted in more agricultural produce, particularly sugar-cane. The quality of iron and steel objects produced during this period was indeed of a high order and some of them were considered to be eminently fit for presentation.

Ktesias (fifth century B.C.) speaks of two swords of Indian steel presented to Artaxeses Mnemon. Later it has been recorded by Quintius Curtius that in the gifts which Alexander the Great received from Porus of Taxila (326 B.C.) were 100 'talents' of steel.

Agriculture

Agriculture registered substantial progress during this period, particularly under the royal control and patronage of the Mauryan rulers. The *Artha-śāstra* which sheds light on the importance attached to agriculture speaks of the science of agriculture and the Director of Agriculture. Likewise the State had accorded a special position to mining and minerals, for the agricultural produce and the minerals determined to a great extent its economy. It gave encouragement to the settlement of people on unoccupied land and vigorously supported agricultural practices. Keen interest was taken in the irrigation schemes as evidenced by the account of Megasthenes who informs us of officers employed by the State to superintend the rivers and inspect the sluices through which the water was let out from the main canals into their branches so as to ensure an equitable supply. Special mention should be made of the well-known Sudarsana Lake in Saurashtra, which was constructed by Pusyagupta under Chandragupta Maurya and restored later by Tusaspa, the Yavana governor under Asoka, for irrigational purposes (6, pp. 356–57).

CLASSICAL AGE AND LATER UP TO *c.* 1200 A.D.

Mathematics

If the Classical Age represents a glorious period in the history of India, verily does it so in the history of Indian science and technology. From about the fourth century A.D. to about the eighth or ninth century and also a couple of centuries later, different branches of science made great headway and even became codified in the form of scientific and technical texts. The astronomical and mathematical texts are of particular significance. There were leading mathematicians who were also well versed in astronomy like Āryabhaṭa I, Bhāskara I, Brahmagupta, Mahāvīra, Āryabhaṭa II, Muñjāla, Śrīpati, Śrīdhara and Bhāskara II. Āryabhaṭa I knew rules for the extraction of square and cube roots, dealt with areas of triangles and trapezia, circles, spheres, arithmetical progression, summation of series, fractions, etc. He enunciated a rule for the solution of indeterminate equation of the first order. He gave the value of π correct to four places of decimal (3·1416) though he knew it was approximate. He also gave the values of 24 sines (*jyā*) for the computation of trigonometrical angles; what is more, he developed an alphabetical system for expressing numbers on the decimal place-value model. The decimal place-value notation itself, using nine digits and zero, was already in use in India by about the fifth century A.D. It is to be

said to the credit of the Indians that they accorded a name, symbol and the right place for zero in an ingenious way. Severus Sebokht, a Syrian scholar of the seventh century A.D., referred to the Indian decimal place-value notation 'a computing that surpasses description' and was full of praise for the dexterity with which it was formulated. The decimal notation spread to Indo-China and Japan probably in the sixth or seventh century A.D., and the Indian numerals found an able exponent in the Arabic mathematician al-Khwārizmi in the ninth century A.D. Al-Khwārizmi's works were translated into Latin in England by Adelard of Bath in the twelfth century and in the next century or so the Indian decimal place-value notation had established itself in Europe and has since become universal.

Of the other contributions of the Indian mathematicians, those of Bhāskara I include a method of solving indeterminate equations of the first degree, while of Brahmagupta a formula for the sum of n terms of the Arithmetic Progression of which the first term is unity and the common difference is unity. The latter was able to state succinctly the rules regarding the volume of the prism, area of cyclic quadrilateral and the formula for the length of two diagonals of a cyclic quadrilateral. He also knew the theory of non-recurring continued fraction and gave the general solution in integers of the indeterminate equations of the first degree. Brahmagupta is well known for his dealing with the indeterminate equation of the second degree: $Ny^2+1 = x^2$. Mahāvīra has given an account of the use of zero and the summation of n terms of a Geometrical Progression. Bhāskara II developed a method known as *cakravāla* or cyclic method for rational integral solutions of the indeterminate equation of the second order. He also worked out a geometric proof of the Pythagorean theorem. There is a view that Bhāskara almost hit upon the root idea of differential calculus, but as he did not conceive of the idea of limit he was unable to evolve the notion of modern calculus which, as we now know, owes its development to Newton and Leibniz.

Astronomy

In astronomy, there came into light a new class of astronomical literature which went under the name of *siddhānta*. Of the recognized 18 *siddhāntas*, five, viz. *Saura*, *Vāśiṣṭha*, *Pauliśa*, *Romaka* and *Paitāmaha*, have been dealt with by Varāhamihira in his *Pañcasiddhāntikā*, and of them, the *Sūryasiddhānta* is considered to be the best and most accurate. Although the date of this treatise is uncertain, its present form, presumably, contains different layers of astronomical ideas, some very old and the others comparatively recent.

It is very likely that the divisions of time, the concept of *mahāyuga*, cosmology, *nakṣatra* system, etc., which are included in this work are among the ancient ideas while, possibly, the epicyclic theory and the associated views might have been later accretions, even so before the time of Varāhamihira. Al-Bīrūnī says that the *Sūryasiddhānta* might have been

formulated by one named Lāṭa who in turn recorded the revelations of a solar divinity to an *asura* named Maya. There is a view that this astronomical compilation is probably Babylonian in origin, equating the *asura* to some Babylonian. Yet another view is that the *asura* Maya is an outlandish form of *Turamaya* (the Sanskrit form of Ptolemy of Egypt).

The *Sūryasiddhānta* deals with measurement of time, sine-tables and cosine functions, meridians, equinoxes and solstices, eclipses, planetary motions, inclination of the *nakṣatras* to the ecliptic, heliacal risings and settings of stars, relative motions of the moon and the sun, some astronomical instruments and calendarial computations. While some of the astronomical ideas are related to the Alexandrian or Greek sources, there are also in the text not a few of the notions characteristically Indian.

The Indian astronomers knew that the equinoctial and solstitial points do not remain stationary and to account for this they thought of a libratory motion instead of a rotatory precession. In the *Sūryasiddhānta* it is stated that in a *mahāyuga* (a period of 4,320,000 years, at the end of which all the moving celestial bodies are presumed to return to their original positions after having completed a whole number of revolutions) the circle of asterism falls back eastward by thirty-score ($30 \times 20 = 600$) revolutions. If the limits of the libratory movement are assumed to be 27° in either direction, it gives an annual rate of the motion of equinox as 54 seconds, which is near to the modern value of about 50 seconds per year.

Of the Indian astronomers, Āryabhaṭa I developed the theory of the rotation of the earth as well as that of the epicycles. Brahmagupta who did not accept the theory of Āryabhaṭa regarding the rotation of the earth was an accredited astronomer not only in India but also in Arabia. His two astronomical treatises, *Brāhmasphuṭasiddhānta* and *Khaṇḍakhādyaka*, were rendered into Arabic by Muhammed ibn Ibrahim al-Fazari and Ya'qub ibn Tariq respectively in the late eighth century A.D., under the Arabic titles of *Sindhind* and *Arkand*. Al-Khwārizmi prepared an abridged version of the former. It is supposed that an Indian astronomer paid a visit to the court of Abbasid Caliph, al-Mansur, taking with him tables of the equations of planets and other astronomical data. Muñjāla worked out the corrections due to the precession of equinoxes in the sense of a retrograde motion and not of oscillation or libration. He even gave a correction for the second inequality of the moon. Śrīpati based his astronomical work, *Siddhāntaśekhara*, on the work of Brahmagupta and dealt with the moon's second inequality. Bhāskara II, following Brahmagupta, further elaborated the ideas concerning the revolution of the planets by epicyclic-eccentric theories. He also analysed the motion of the sun by considering the changes in longitude (2, pp. 92–124).

Medicine

The *Āyurveda* continued to maintain its high tradition and was included as one of the important subjects of study in the general curriculum

of the universities at Nalanda, Srivikramasila and Valabhi. The Buddhist scholars attached great importance to the medical profession which enabled them to serve the sick and the emaciated as a part of their religious and social obligation. The noted medical writers of this period, Vāgbhaṭa and Nāgārjuna, were Buddhists. Vāgbhaṭa's *Aṣṭāṅgahṛdaya* was by far the most concise exposition of the Āyurvedic knowledge. Important commentaries on this work were written by Aruṇadatta, Candrānanda, Hemādri and Indu. Another valuable clinical guide dealing with the medical diagnosis was the *Rugviniścaya* by Mādhava, also known as the *Mādhavanidāna* (a compilation from the *Caraka*, *Suśruta* and *Aṣṭāṅgahṛdaya*), on which Vijayarakṣita (*Madhukośa*) and Vācaspati (*Ātaṅkadarpaṇa*) wrote commentaries. Vṛnda and Cakrapāṇi produced valuable medical treatises in the form of *Siddhayoga* and *Cakrasaṃgraha* respectively (**4**, pp. 226–27).

The Arabs had an intimate knowledge of the Indian drugs when they established trading centres on the Malabar coast in the seventh century A.D. Later, when Sind was conquered by them, there was an active interchange of scholars well versed in different sciences. The Abbassid Caliphs gave great encouragement to the translation of the Indian medical texts. An emigrant Indian scholar translated the *Suśruta Saṃhitā* into Arabic under the title of *Kital-Samural-hind-i* of 'Susṛud'. Ali ibn Zain translated the *Caraka Saṃhitā* into Arabic as the treatise of 'Sarag'. The *Mādhavanidāna* and *Aṣṭāṅgahṛdaya* were also rendered into Arabic under the titles of 'Badan' and 'Astankar' respectively (**4**, pp. 259–62). It is reported that Khalid, the Vazir of Caliph al-Mansur, was the son of the chief priest in a Buddhist monastery in Balkh. The chief priest was called a Barmark. When Balkh was conquered by the Caliphs, Khalid's mother was also captured and the son, who was converted into Islam, became the founder of the Barmaki[a] family which is recognized to be responsible to a great extent for introducing Indian medicine, arithmetic and astronomy into Arabia. Under its direction the medical, pharmacological and toxicological texts in Sanskrit were among the Indian scientific texts rendered into Arabic. Later, al-Razi or Rhazes (A.D. 865–925) incorporated the Indian medical knowledge in his comprehensive book known to medieval Europe as *Liber continens* (*kitab-al-hawi*) which was translated into Latin by Moses Farachi (*c.* thirteenth century A.D.) and which became the standard medical work of the Middle Ages.[b]

In this period there were also two other schools of medicine, the *Rasacikitsā* and the *Siddha*, which mainly employed minerals or metallic compounds as well as the naturally occurring salts as medicines. The quasi-religious practices and tantrik procedures are an integral part of these two systems (4, pp. 232–33) which extol mercury, sulphur, mica and the like as possessing divine healing powers, and are invariably linked with the alchemical and iatro-chemical practices.

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[a] Majumdar (R. C.), IV, pp. 450–51.
[b] Singer, pp. 148 and 162.

Alchemy and Iatro-chemistry

By about the sixth or seventh century A.D. when the tantrik beliefs and practices were finding adherents in different strata of society, a new way, esoteric in essence, of understanding certain chemical substances and of processing them by an experimental technique of an entirely different character, made its appearance in India. Known as *rasavidyā* and centring round mercury, the *rasa* which was held in veneration because of its presumed divine origin as the creative essence of Śiva, this new approach developed into a complex system of thought and practice so as to aid the tantrik attainment of the eight *siddhis* (*aṇimādi*). It was also a manifestation of human inclination to surpass rigidities, be they of caste, sex or creed, that had taken firm roots in the Indian society. The *tantras* offered a system of thought and practice obliterating these rigidities by mystical ways which, it was tacitly assumed, would ensure a state of perpetual youth to the body and a divine experience to the mind. In respect of the former, mercurial preparations and compositions of a number of other chemical substances, principally mica and sulphur, were considered to be extremely potent for the preparation of the *elixir of life*. On deeper analysis, it would seem that this particular strand of thought, alchemical in content, owes its origin to the other culture-areas, notably China and Arabia, with which India had intimate contacts during this period.

In its fully developed form, the mercury-based alchemy in India relates to the male-female symbolism (mercury and sulphur presumed to be the principles of Śiva and his consort respectively) and its association with cinnabar (mercuric sulphide) which was assumed to be the main life-prolonging essence.

It is not unlikely that the Indian alchemy obtained its seed ideas from the southern regions of China where a similar type of alchemical thought based on *Yin* (female) and *Yang* (male) which extolled cinnabar in the same way is noticed. Nevertheless, the *rasavādins* adapted them in such a way that in a century or two the alchemical knowledge became formalized in a way characteristically Indian. The twin aspects of alchemy, viz. preparation of the *elixir of life* and transmutation of base metals into gold or silver, were fostered with considerable ingenuity, although the former was the main concern of the alchemists in India.

The *rasavidyā* gradually developed into a methodical knowledge and a number of texts which presented a wide variety of alchemical knowledge appeared from about the tenth century onwards. The *rasaśāstra* texts, as they came to be known, describe a number of chemical substances under the *mahārasas*, *uparasas*, *navaratnas*, *dhātus*, poisons and plants as also many apparatus (5, pp. 322–33), some of them complicated, used for processing these substances. A detailed study of these texts reveals how skilled were the *rasavādins* in performing a number of 'purificatory' processes in order to remove the deleterious effects of the metals and minerals so that the latter would become eminently fit for internal use. Of them, the eighteen *saṃskāras* of mercury merit particular mention. They include rubbing

with various medically efficacious plant juices and extracts, incorporation of sulphur, mica, certain alkaline substances, etc. The *rasavādins* believe that mercury, after it has undergone sequentially the seventeen processes, has all the powers of transmutation. At this stage it should be tested for its powers and, if the test is positive, it should be used for the eighteenth process leading to its assimilation into and the rejuvenation of the body (5, pp. 320–22). This concept seems to be peculiar to Indian alchemy.

There is yet another alchemical practice peculiar to India and this relates to the prime substance known as *muppu* which occupies an important place in the Tamil works on alchemy. Regarded as the union of three naturally obtained salts (*pūnīru*, *kalluppu* and *aṇḍakkal*), *muppu* is recognized as of four types, viz. *vāda muppu*, *vaidya muppu*, *yoga* and *jñāna muppu*. The first is used in the Tamilian alchemy, the second in the Siddha system of medicine, the third and fourth seem to connote their effect on spiritual practices. It would appear that the Tamilian *muppu* corresponds to the later European concept of 'Philosophers' Stone', for the *muppu*, with compounds of mercury added to it, is presumed to possess extraordinary potency of transmuting baser metals into gold as well as rejuvenating the human system. There seemed to be a number of methods of preparing *muppu* of the desired potency and these are kept as closely guarded secrets by the practitioners of the *Siddhavidyā* and alchemy (5, pp. 334–38).

There are a number of medical texts dealing with alchemy in Tamil and a careful study of them may be of great value from the point of view of the history of the movement of alchemical ideas. For, one of the reputed Tamilian alchemists, by name Ramadevar, says in one of his works[a] that he visited Arabia, assumed the name of Yaqub and taught the *muppu* salt-based alchemy there (perhaps in the eleventh or twelfth century A.D.). Interestingly enough, in the fifteenth century Paracelsus, a Swiss physician, gave a new direction and meaning to alchemy by introducing *salt* as the third fundamental principle in addition to mercury and sulphur, and by exhorting that alchemy was to engage itself in the noble task of transforming the naturally occurring minerals into medicinal compositions beneficial to humanity. It is well known that such an attitude had already found roots in the Siddha system of medicine and also in the iatro-chemical *rasaśāstra* texts in India.

In particular salt was given a proper place in addition to mercury and sulphur in the Tamilian alchemy. Perhaps protracted studies may bring to surface the historical link in the movement of alchemical ideas between India and the west.

Atomism

In the Classical Age and the succeeding centuries the philosophical works of the Nyāya and the Vaiśeṣika systems and some of the Bauddha

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[a] *Cunnakāṇḍam* 600 by Yaqub, verse Nos. 227 and 466.

and Jaina schools, which came out with full intellectual vigour presenting strong epistemological positions, are of great importance. In them is found a rational explanation of the basic stuff of the gross world in terms of atoms. The *Nyāya-Vaiśeṣika* texts, in particular, describe in detail and in a logical way the formation of gross bodies from the atoms through dyads (*dvyaṇuka*) and triads (*tryaṇuka* or *trasareṇu*). The four *bhūtas—pṛthvī, ap, tejas* and *vāyu*—are considered to be atomic in their eternal states. The two atoms are regarded as the material cause for the coming into being of a dyad which is an effect. Three dyads are the cause for producing a triad which is again an effect. The cause brings about the effect, but is absorbed immediately into the latter which in turn assumes the role of a cause to continue the sequence. The noteworthy characteristic of Indian atomism is the causal garment associated with it. Further, according to the *Nyāya-Vaiśeṣika*, two like atoms unite only in the presence of another type of atom, the latter functioning as an accessory cause, and this explains conclusively the presence of different qualities in a single substance. Also, it is pointed out that the structural arrangement (*vyūha*) of the dyads in a triad gives rise to different qualities in a substance. Such a profound concept, which can bear testimony even from the modern chemical point of view, is not found in the early schools of atomism elsewhere including the Greek atomism (9, pp. 461–69).

In the west, the atomic views of Greek thinkers found an able exponent in Lucretius (first century B.C.), but later for reasons unknown[a] practically receded to the background for over a thousand and six hundred years, for it was only in the seventeenth century A.D. that Gassendi, Boyle, Newton and Huygens revived them with certain modifications. On the other hand, the Vaiśeṣika atomism found a number of protagonists for over two thousand years right up to the eighteenth century A.D. Though sometimes bordered on polemics, the Indian atomism was virile enough to attract into its fold the intellectuals of different dispositions either as adherents or opponents.

Impetus Theory

Yet another Indian physical concept of considerable relevance to the history of science, which found adequate expression in the Vaiśeṣika texts, the *Praśastapādabhāṣya* and the *Vyomavatī*, relates to the notion of impetus to account for continued motion of a body. It is postulated that when the body experiences the first unit of motion, a quality of impetus (*vega*) is possessed by it; and as a result the body continues to move in the same direction. However, when the moving body encounters an obstacle, it would come to rest or continue its motion with diminished strength according as the latter neutralizes the quality of impetus fully or partially. The texts also describe the motion of bodies like an arrow, javelin and pestle.

[a] It may be noted that Aristotle opposed the atomic views of his predecessors and it was the Aristotelian interpretation of the physical world that held a dominating position in Europe for a long time.

It is interesting to observe that in the west it was not before the fourteenth century A.D. that we come across a theory of impetus which permitted a description of continued motion of a projectile. Till then the Aristotelian views of the motion in terms of the projector transforming to the immediate layer of air (medium) the power to thrust the projectile, the layer transferring its impulse to the next layer of air and so forth held the field, although in the sixth century A.D. John Philoponus of Alexandria, who did not concur with this view, suggested that the projector imparted a motive power to the projectile itself. The Vaiśeṣika conception of impetus in all its details is a distinct forerunner of what was later developed in the west on mathematical lines (9, pp. 472–75).

Biological Sciences

Plants and animals received adequate attention of poets of nature, lexicographers, encyclopaedists and philosophers who in their works have given considerable details of their types, characteristics, habitats, etc. Kālidāsa in his great lyrics and dramas has given a vivid description of the plant and animal life, particularly of the birds and insects. Amara describes a wide range of plants and animals along with their synonyms according to their habitats and habits. In the *Bṛhatsaṃhitā* is found an account of plant pathology (7, p. 385) and of animals including cow, dog, cock, goat, horse, elephant, etc. Praśastapāda, the well-known exponent of the Vaiśeṣika system, attempts at a simple but meaningful classification of animals and plants. The animals are categorized into *ayonija* (asexually produced) and *yonija* (sexually produced), the latter being further subdivided into *jarāyuja* and *aṇḍaja* (8, pp. 426–27). Plants are classified into *vṛkṣa*, *tṛṇa*, *oṣadhi*, *gulma*, *latā*, *avatana* and *vanaspati*.

A work of considerable interest from the point of view of the botanical knowledge of this period is *Vṛkṣāyurveda* of Parāśara. Though presumed to be a text belonging to the first century B.C. or first century A.D., there is no doubt that it has many later accretions. In any case, this text gives succinctly an outline of plant morphology and certain aspect of plant physiology, as also a graphic description of the germinating process. It presents a system of nomenclature based on three factors, viz. the botanical significance, therapeutic value and habitat (7, pp. 379–80).

Technological Practices

As to the technological practices of the Classical Age, metal-working was in a flourishing state. The historic vestiges like the Iron Pillar at Delhi and the copper statue of the Buddha at Sultanganj in Bihar bear eloquent testimony to the skills of the metalsmiths of the time. The Iron Pillar which has a height of about 24 feet and a weight of more than six tons is made of wrought or malleable iron (99·72%) and has remained still without any signs of rust even though it is about 1,500 years old. The huge statue of the Buddha—about seven feet six inches in height and nearly

a ton in weight—was cast in two layers with great dexterity (5, pp. 299–300). There is no doubt that the metal-workers displayed spectacular skills in producing new appliances and utilitarian forms. The art of jewellery using precious metals and stones was in a flourishing form. There were in different parts of the country centres well known for metal industry producing exquisite metallic forms; and *dhātuvāda* (metal-working) came to be regarded as one of the 64 *kalās*. Hiuen Tsang, the Chinese pilgrim, describes a huge copper image of the Buddha (80 ft. in height) and a brass temple (height expected to reach over a 100 ft.) by Emperor Harsha. Though the furnaces employed for winning the metals from their ores were small and primitive from the modern standards, the metal-workers had developed the necessary expertise and aimed at excellence. In south India, bronze-working in an elegant style was in a flourishing state. Similarly, advanced state of workmanship and sophistication were exhibited in the production of ceramic ware of high appeal. Special types of glossy pottery were produced using mica dust and in graceful designs. At Ahicchatra have been observed cylindrical pits of large dimensions and it is probable that these were the special types of kilns for the turning and baking of ornamental pottery and tiles.

Agriculture

But the more important component of the economic well-being of the people of the Classical Age, and a couple of centuries succeeding it, was, undoubtedly, agriculture as evidenced by rather a wide variety of agricultural products raised in different parts of the country and also the royal encouragement given to irrigation works. In addition, the use of *araghaṭṭa* for irrigation purposes was on the increase. As the State had realized the importance of the cultivation of waste lands, land-grants were made in an increasing measure on many an occasion. Agricultural practices received adequate attention of codifiers like Amara and Varāhamihira who included them in their well-known compilations. Some of the other works like the *Nāradasmṛti*, *Bṛhaspatismṛti*, *Viṣṇudharmottara* and the *Agnipurāṇa*, too, dealt with agricultural and allied practices. What is more, time was ripe for the appearance of even specific texts like the *Kṛṣi-Parāśara* (6, p. 358) and the *Vṛkṣāyurveda* (6, p. 362) which, exclusively devoted to agriculture and horticulture, became reference manuals. Cryptic sayings in the regional languages like Bengali, Maithili and Tamil portraying agricultural practices entered the folklore, and the farmers spared no efforts in living up to them.

The foregoing bird's-eye account shows how the different branches of science had taken roots in India by about the twelfth century or so and how India participated effectively in the evolution and even transmission of scientific ideas and techniques. It is refreshing to note that Said-al-Andalusi, an astronomer and historian of science in the eleventh century A.D., accords in his work, *Kitāb Tabakat al-Umam* (the Categories of Nations), the first place to India among the contemporary nations which

had developed sciences then. In the next two or three centuries which in the west provided the decisive converging historical and social influences to usher in the Renaissance later, India's scientific output began to show signs of decay. The foreign invasions and internecine strifes, which unleased forces of disruption and unsettlement on the one hand and the rigid caste-ridden social structure which was impermeable to new outlook and endeavours on the other, seemed to be too powerful to stimulate scientific thinking. In effect, history did not appear to be on the side of India during the crucial two or three centuries so that India could participate in the Renaissance and thus become one of the early homes of modern science.

MEDIEVAL PERIOD

In the medieval period from about the twelfth century to the end of the eighteenth century A.D., the history of science and technology in India developed two facets, one concerned with the already chartered course of the earlier tradition and the other with the new influences which came up as a result of the Islamic and later the European impacts. These two did not always run parallel, nor were they invariably complementary to each other. But they existed side by side, sometimes endeavouring to assimilate the impact of each other. A noteworthy feature was that several important scientific works, particularly in astronomy and medicine, were rendered from Sanskrit to Persian or Arabic and vice versa. Though in respect of scientific ideas the mutual impact was not so appreciable and each strand of scientific thought proceeded generally along the established path, the technological practices undoubtedly underwent perceptible changes and, in fact, some new technological developments took place in such fields as paper, gunpowder, enamelling, glass and metal-working. In addition, certain types of new plants and fresh horticultural practices also appeared. These developments, however, looked dwarfs before the new intellectual endeavours that Europe witnessed in the fifteenth and sixteenth centuries and the gigantic strides of modern science and technology thereafter. The Indian astronomy, mathematics, physics, chemical practices, plant and animal sciences chose to move in the previously determined grooves and so were unable to develop a fresh method and an attitude conducive to the development of modern science. Most of the scientific works which appeared in the medieval period were in the nature of commentaries or expositions of the earlier treatises.

Astronomy

In astronomy, after Bhāskara II, a number of commentaries dealing with the already established astronomical notions appeared.

Mahendra Sūri, who flourished in the court of Emperor Firoz Shah Tughlak as one of his court astronomers, wrote a tract called *Yantrarāja*

dealing with astronomical instruments.[a] Parameśvara, who belonged to Kerala, was a prolific commentator on the *Sūryasiddhānta*, *Mahābhāskarīya*, etc. In Kerala were families of astronomers and almanac-makers. Nīlakaṇṭha Somasutvan, who was the disciple of Parameśvara's son, was a noted commentator of *Āryabhaṭīya*. He also wrote a few original works containing refined methods of astronomical calculations. Cakradhara, Makaranda, Lakṣmīdāsa, Jñānarāja and Gaṇeśa Daivajña were the other commentators. In his *Grahalāghava*, Gaṇeśa Daivajña avoided trigonometrical calculations and introduced simple arithmetical methods instead. There were also families of astronomers in Maharashtra and of them special mention should be made of the Divākara family. Divākara was himself a disciple of Gaṇeśa Daivajña and his family produced well-known commentators such as Viṣṇu, Nṛsiṃha and Kamalākara. To another family of astronomers represented by Vallāla, who migrated from Madhya Pradesh to Banaras, belonged Kṛṣṇa Daivajña who wrote valuable commentaries on the works of Bhāskara II. His brother, Raghunātha, produced a commentary on the *Sūryasiddhānta* and Raghunātha's son, Muniśvara, brought out *Marīci*, a commentary on the *Siddhāntaśiromaṇi* of Bhāskara II. Islamic astronomical ideas had penetrated already into the minds of some Indian astronomers of whom Kamalākara was reputed for lending his suppot to the former. Maharaja Sawai Jai Singh II of Jaipur was greatly interested in astronomy and was well acquainted with Ptolemy's *Almagest* and Euclid's *Elements* in Arabic versions, as also with the works of the Marāgha school of astronomers like Naṣīrū'd-din-aṭ-Ṭusi, al-Gurgani, Jamashid Kashi and Ulugh Beg. He even had considerable knowledge of the European astronomy. It was Jai Singh who set up the five observatories which stand as monuments to his deep interest in astronomy at Delhi, Ujjain, Banaras, Mathura and Jaipur.

Comprising massive instruments in masonry, these observatories enabled him and the astronomers associated with his work to record a number of observations which formed part of his astronomical table, the *Zīj Muhammed Shahi*, compiled both in Persian and Sanskrit. In this task, he had the able assistance of his principal astronomer Jagannātha Paṇḍita. The instruments, *Jai Prakāsh*, *Rām-yantra* and *Samrāṭ-yantra*, are Jai Singh's own inventions. Jagannātha translated Ptolemy's *Almagest* into Sanskrit under the title the *Samrāṭ-siddhānta* (2, pp. 101–103).

Mathematics

Nārāyaṇa Paṇḍita, son of Nṛsiṃha Daivajña, was well known for his work on arithmetic, *Gaṇitakaumudī*, and on algebra, *Bījagaṇitāvataṃsa*, on which later a number of commentaries appeared. Gaṅgādhara of Gujarat wrote a commentary on the *Līlāvatī* and his brother, Viṣṇu Paṇḍita, produced

[a] The versatile metallic instrument, astrolabe, was introduced into India by the Muslims and it was already in use during the reign of Shah Jahan. Lahore was reputed for the production of astrolabes of high quality.

an arithmetic called *Gaṇitasāra* on the model of Śrīdhara's work. Parameśvara's commentaries included among others *Bhaṭadīpikā* (on the *Āryabhaṭīya*), *Karmadīpikā* and *Siddhāntadīpikā* (on the *Mahābhāskarīya*), the *Līlāvatī-vyākhyā*. In Kerala there also came into light works such as *Karaṇapaddhati*, *Gaṇitayuktibhāṣā* and *Sadratnamālā* which gave rules for trigonometrical sine, cosine, tan and π series. Nīlakaṇṭha Somasutvan produced *Tantrasaṃgraha* which also contains rules of trigonometrical series.

Apart from his profound scholarship in Indian astronomical calculations, Gaṇeśa Daivajña produced *Buddhivilāsinī*, a commentary on the *Līlāvatī*, containing a number of illustrations. Kamalākara's brother, Raghunātha, composed a commentary entitled *Mitabhāṣiṇī* on the *Līlāvatī*. Kṛṣṇa of the Vallāla family brought out *Navāṅkura* on the *Bījagaṇita* of Bhāskara II in which is found an elaboration of the rules of indeterminate equation of the first and second orders. Nīlakaṇṭha Jyotirvid, who was in the court of Akbar, compiled *Tājik* (also an astrological work) introducing a large number of Persian technical terms. Faiẓī, at the behest of Akbar, produced a Persian version of the *Līlāvatī*, and Aṭa Ullah Rashidī translated Bhāskara's *Bījagaṇita* during the reign of Shah Jahan. Jagannātha who, as stated before, was in the court of Maharaja Sawai Jai Singh of Jaipur, translated Euclid's *Elements* under the Sanskrit title of *Rekhāgaṇita*, from the Arabic version *Taḥrīr-u Uqlīdas* by Naṣīru'd-din-aṭ-Ṭusi. The Samarqand school of mathematics and astronomy also penetrated into India, particularly during the Mughal period. Both Babar and Humayun evinced keen interest in mathematics and astronomy. Akbar caused the introduction of mathematics as a subject of study among others in the educational system. Interesting it is to note that in the different libraries in India there are a number of Arabic versions of Euclid's *Elements* and its commentaries, geometrical works of Archimedes and copies of works of mathematicians of the Middle East and Central Asia. Naṣīru'd-din-aṭ-Ṭusi, the founder-director of the Marāgha observatory, was recognized as the authority among the Muslim scholars. Arabic versions of his works are also available in some of our libraries.

Medicine

Though *Āyurveda* did not progress as vigorously as it did in the ancient period, some important treatises like the *Sāraṅgdhara Saṃhitā*, the *Cikitsāsaṃgraha* by Vaṅgasena (a redaction of the earlier *Saṃhitā* by Agastya who was one of the Siddhas of south India), the *Yogaratnākara* (popular in south India) and the *Bhāvaprakāśa* of Bhāvamiśra were compiled. The *Sāraṅgdhara Saṃhitā*, a text of the thirteenth century includes opium in its materia medica and employs pulse and urine examination for diagonostic purpose, possibly following Chinese and Arabic practice. The *Bhāvaprakāśa* contains an exhaustive list of diseases and their symptoms, as also of drugs current in his time. The etiology of syphilis which was introduced into India by the Portuguese seamen in the fifteenth century is also discussed in the

text. The drugs mentioned include metallic preparation of the *rasacikitsā* system and even imported drugs.

As to the *rasacikitsā* system, it started as non-Āyurvedic in its approach and dealt principally with a host of mineral medicines, both mercurial and non-mercurial. Some esoteric views concerning mercury, mica, sulphur, copper sulphate, etc., also got mixed up with the therapeutic procedures of this system. Though initially subscribed to the male-female symbolism and adopted a classification of substances in tune with this symbolism, the *rasacikitsā* school gradually adopted the *pañcabhūta* doctrine, supposing that mercury, the main pillar of this system, was an embodiment of all the *bhūtas*. The Siddha system, mostly prevalent in Tamilnad and attributed to the reputed Siddhas, who were supposed to have evolved many a life-prolonging composition, is particularly rich in mineral medicines. The efficacy of these medicines is sought to be enhanced by the use of specially processed naturally obtained salts known as *muppu*. There was no doubt an interaction between the *rasacikitsā* school and the Āyurvedic system to mutual advantage.

Another important system of medicine which flourished in India in the medieval period is the *Unāni Tibb*, sometimes referred to as Arabian medicine by the western historians, for it came down to them through the Arabic medical writers. It is also known as *Unāni* because it is based upon the Greek system of medicine (*Unāni* being an outlandish name for Ionia of the Greek Archipelago). It should be emphasized that the Greek medicine when it reached Arabia underwent certain modifications at the hands of Arabic medical writers who also incorporated into it some of the Persian as well as the Indian medical traditions. Ali bin Rabban summarized the whole system of Greek medicine as well as the Indian medical knowledge in his book, *Firdausu-l-Hikmat*. His disciple, al-Razi or Rhazes, studied both the systems. The work of Avicena, the most famous Arabic medical writer, is known as *Qānūn* (the Canon) which has been accepted in India as the greatest authority of *Unāni Tibb*.

The *Unāni* came to India along with the Muslims by about the eleventh century and soon found a congenial environment for its growth. During the reign of Alauddin Khalji there were already a number of Hakims of repute. Muhammed bin Tuglaq was not only a patron of *Unāni* but also well versed in the *Unāni Tibb*. At his instance Hakim Diya Muhammad compiled a book, *Majmū'-e-Diyaē*, incorporating the Arabic, Persian and Āyurvedic medical knowledge. Firoz Shah Tughlaq who had a comprehensive knowledge of *Unāni Tibb* wrote a book, *Tibbe Firozshahi*. During the time of Sikandar Lodi the Hakims and the Vaidyas worked together. Mian Taha, the Amir of Sikandar Lodi, is said to have remembered by heart as many as 24,000 verses on Indian medicine. Apart from the Delhi Sultans, the provincial Muslim rulers in Gujarat and the Deccan encouraged Hakims and Vaidyas and caused either translations or independent medical works to be written. But it was in the period of the Mughals that the *Unāni Tibb* registered rapid progress and became increasingly

popular. The Hakims were held in high esteem and enjoyed royal patronage. The rewards and remunerations paid to them were so attractive that not a few highly qualified Hakims from Iran and other places came to India and worked in many new free public hospitals which the Mughal rulers established in all the cities under their control. A fact that should not go unnoticed is that in these hospitals thousands of Hakims and the Āyurvedic Vaidyas worked side by side. Lahore, Delhi, Lucknow, Patna, Murshidabad, Hyderabad and Madras were the important centres of *Unāni Tibb*, which had well-qualified *Unāni* hospitals and *Madrasas* of *Tibb*. A good number of medical works also appeared during the Mughal rule. The *Tibbi Aurangzebi*, dedicated to Aurangzeb, is based on Āyurvedic sources. The *Musalajati-Dārshikohi* of Nuruddin Muhammad, dedicated to Darashikoh, deals with Greek medicine and contains at the end almost the whole Āyurvedic materia medica.

Some independent contributions to the *Tibbi-Unāni* were also made by Hakims on the basis of their own experiences of medical cases which they handled with great care and originality. They developed treatment of the venereal diseases and made fresh contributions to epidemology, toxicology, therapeutics and *Unāni Materia Medica*.

Study of Animals and Plants

In the thirteenth century A.D., Haṃsadeva compiled, at the instance of Saudadeva, the Jaina king of Jinapura, a work known as *Mṛga-pakṣī-śāstra* which gives a general, though not always, scientific account of some of the beasts and birds of hunting. The Muslim kings of India, as warriors and hunters, maintained a fleet of pedigree animals, such as horses, dogs, cheetahs and falcons. The Mughal kings who were fascinated by the animals, both domesticated and wild, have described in their memoirs and biographies the distinctive characters, ecology, anatomical aspects, local names, etc., of the animals which were in their menageries. Babur and Akbar, amidst their political preoccupations and war, found time to fondle and study them. Akbar evinced special interest in producing good breeds of domestic animals, elephants and horses; and the breeds of horses in his stables were as fine and sturdy as those of Arabia. His possessions included as many as about 9,000 cheetahs or hunting leopards, a species practically extinct now in India. The greatest naturalist of the Mughal kings was undoubtedly Jahangir who in his *Tuzuk-i-Jahangīrī* recorded his observations and experiments of breeding trials and hybridization. He described about 36 species of animals. His court artists, specially Mansur, produced elegant and accurate portraiture of animals, some of which are still preserved in several museums and private collections.

As a naturalist, Jahangir was interested in the study of plants, and his court artists in the floral portraiture. Some 57 plants have been described in his work, as also the types of inflorescence, pollination and methods of fruit preservation.

Chemical Practices

Of the new technological practices which soon established themselves in the medieval period, special mention should be made of paper-making, gunpowder and pyrotechnics. The art of paper-making was introduced into India probably in the eleventh century A.D. from Nepal which in turn might have obtained the technique of paper production from China. Before the introduction of paper, the ancient literature was preserved generally on palm-leaves in south India and birch-bark in Kashmir and northern regions of the country. About the fourteenth or fifteenth century A.D. paper began to be used and, in the later half of the fifteenth century, Kashmir was producing paper of attractive quality from the pulps of rags and hemp with lime and soda added to whiten the pulp. Sialkot, Zafarabad, Patna, Murshidabad, Ahmedabad, Aurangabad and Mysore were among the well-known centres of paper production. Zafarabad was significantly known as *Kaghalishaher* (paper city) and produced glossy and strong paper from bamboo pulp. Ahmedabad's paper was of export quality, glossy and in different sizes and colours. During Tippu's time, Mysore possessed a paper-making factory producing a special type of paper having gold surface. The technique of paper-making was practically the same throughout the country, differing only in the preparation of the pulp from different raw materials. The Mughal rulers and the Peshwas gave considerable encouragement to the production of paper which became an important vehicle of royal communication and legal transactions.

Gunpowder was an article of warfare at the beginning of the sixteenth century. The Mughals knew the technique of production of gunpowder and its use in gunnery. The Indian craftsmen were quick to learn the technique and evole suitable explosive compositions. The *Śukranīti*, a sixteenth- or seventeenth-century treatise in Sanskrit attributed to Śukrācārya, contains a description of how the gunpowder can be prepared using saltpetre, sulphur and charcoal in different ratios for use in different types of guns. Such formulations were not unknown in India earlier, because certain composition of fireworks were already in use. The available evidence seems to indicate that pyrotechnic practices were current in India even in the thirteenth or fourteenth century. There are works dealing with pyrotechnics in Sanskrit, Marathi, Tamil, Malayalam and Persian. The principal types of fireworks included those which pierce through air (rockets), produce sparks of fire, blaze with variegated colours and end with explosion. Generally metal-dusts were used for the production of sparklings of different colours. Spectacular display of fireworks was a common feature in marriages, major religious festivals and royal ceremonies in medieval India as even now.

The metalsmiths, particularly in the central, eastern and southern parts of India, were known for the production of intricate forms of both copper and bronze images which were being produced on a large scale by the well-known *cire perdue* process. Metal icons were fabricated according to

the traditional measurements in an attractive style, erecting several figures even on one pedestal. Iron-smelting and forging operations were also followed with further achievements such as the production of large iron pillars for use in temples, and of damascened swords using steel of high quality. The latter were in great demand in foreign countries at that time. Cosmetics and perfumes were becoming increasingly popular and some new compositions also appeared to cater to the needs of the royal baths and religious ceremonies, particularly during the Mughal period. *Āin-i-Akbarī* speaks of the 'Regulations of the Perfume Office of Akbar'. The *āttar* of roses was a popular perfume, the discovery of which is attributed to the mother of Nurjehan.

Agriculture

As to agriculture, the pattern of raising food crops practically remained the same as in early India. However, important changes occurred in the introduction of new crops, trees as well as horticultural plants by the foreign traders and enforcement of new land tenure system by the rulers. The principal crops were wheat, rice, barley, millets, pulses, oilseeds, cotton, sugar-cane and indigo, and of them the cultivation of cotton was on the increase and that of sugar-cane more widespread in Mughal times. The Western Ghats continued to yield black pepper of good quality and Kashmir maintained its tradition for saffron and fruits. Ginger and cinnamon from the Tamilnad, cardamom, sandalwood and coconuts from Kerala were becoming increasingly popular. Indigo plantation was widespread in Bengal and Khandesh, and the best quality came from Bayana region near Agra. Tobacco, chillies, potato, guava, custard apple, cashew and pine-apple were the important new plants which made India their new home in the sixteenth and seventeenth centuries. Malwa and Bihar regions were also well known for the production of opium from the poppy plants. On the Western Ghats the cultivation of coffee plants had just begun in the seventeenth century. Improved horticultural methods were adopted with great success. The systematic mango-grafting, introduced by the Jesuits of Goa in the middle of the sixteenth century, improved the native fruit to a phenomenal extent. During Shah Jahan's rule the plantation of temperate climate fruits, till then confined to imperial gardens, was extended to other suitable areas and this resulted in an extensive cultivation of fruit trees in the country.

As regards irrigation, wells, tanks and canals continued to be the principal means of irrigation. In the Panjab *arhat* or *rahat* (Persian wheel), in the Agra region the *charas* (a sort of a bucket made of leather used to lift water with the help of yoked oxen) and at places where the water-level was high the *denkli* were the water-lifting devices. In the south, tanks were constructed in increasing numbers. In the north, canals like the Eastern Jamuna canal and *Nahr-i-d-Bihist* conveyed water from long distances to the fields. Of the agricultural implements, special mention

should be made of a seed-sowing machine, consisting of a wooden bowl with three or four tube outlets so as to deposit seeds behind the coulters, which was already in use in the early part of the eighteenth century. In the medieval period agriculture was placed on a solid foundation by the State which brought about a system of land measurement and land classification, beneficial both to the rulers and the tillers.

WESTERN SCIENCE IN INDIA UP TO *c.* 1900

Modern science, noted for its methodology of induction and concerned essentially with the phenomenal world as against the noumenal, developed firm roots in Europe, particularly in Italy, France, England, Germany and Scandinavia in the sixteenth and seventeenth centuries. It so happened that in these two centuries the Portuguese, Dutch, French and the British had established commercial and colonial interests in India. The versatile Europeans who came to India as missionaries, explorers or administrators were attracted by the flora, fauna, minerals, geographic features, climatic conditions and the like; in other words, by the natural treasures of India. Even though the Britishers, who ultimately became the paramount rulers of India in the later half of the eighteenth century, were by and large instrumental in the promotion of modern science in India for over a hundred and fifty years, India had already the glimpses of modern scientific investigations in the sixteenth and seventeenth centuries.

Beginnings of Botanical Investigations

Garcia da Orta, the Portuguese physician, who came to Goa in 1534, studied and nursed a number of Indian medicinal plants, and his *Colloquies* contains an account of local fruits and plants. Later Hendrich Van Rheede, the Dutch Governor of Malabar Coast, also investigated a number of plants and seeds with the help of some European surgeons with whom he came into contact and the local medical practitioners whom he employed for the purpose. In the eighteenth century, botanical investigations took rapid strides. On the Madras coast the Dane, John Gerhard Koenig, who joined the Tranquebar Mission as a surgeon and later became the Natural Historian of the East India Company in the Madras Presidency, gathered huge specimens of plants and sent many of them to the University of Lund in Sweden. At Calcutta, Robert Kyd paved the way for the establishment of the Royal Botanic Garden for nursing commercially beneficial plants. The Garden, which came into being in 1787 at Sibpur on the west bank of the River Hooghly, became a place of botanical studies through the efforts of William Roxburgh. The Indian Linnaeus and Father of Indian botany, as Roxburgh was known later, drew up a catalogue of about 3,500 species growing in the Garden and, employing local artists, prepared illustrations of a number of plants, which appeared in

1814 under the name *Hortus Bengalensis*. He also produced *Flora Indica* and *Plantae Coromandaliane* (**10**, pp. 491–93).

Survey

Early in the eighteenth century, the French geographer, Delise, published a fairly accurate map of the southern coast of India (1723) and Bourignon d'Anville prepared the well-known *Carte de l'Inde* (1752) based upon the then available knowledge brought to him by the Jesuit missionaries. But, a systematic survey of the country was achieved only by the Britishers after they established their rule in India. Thus Plainsted began the survey work of the coasts of Chittagang (1761) and Hugh Cameron, of the 24-Parganas. Rennell, who was appointed by Clive as the Surveyor-General, produced the first *Map of Hindoostan* in 1783. In the Madras Presidency, Robert Kelly and Michael Topping were the pioneers, and the latter also founded the Madras Observatory and a surveying school. Towards the close of the eighteenth century substantial progress was made in both the land and coastal surveys (**10**, pp. 493–94).

Asiatic Society

An event of far-reaching importance occurred in 1784 and that was the establishment of the Asiatic Society which in the subsequent years rose to be a learned society of pivotal importance not only for initiating and influencing a number of scientific investigations but also establishing certain important scientific organizations. William Jones, the Founder-President of the Asiatic Society till his death in 1794, provided the initial stimuli so that the Society could make rapid progress towards its objective, namely, 'Man and nature—whatever is performed by the one and produced by the other within the geographical limits of Asia' (**10**, p. 495).

NINETEENTH CENTURY

In the history of modern science in India the nineteenth century is the most important period, for it was during these hundred years that there was a gradual expansion of the scientific pursuits in botany, geology, trigonometrical survey, meteorology, zoology, archaeology, etc., on the one hand and the establishment of the service organizations like the Trigonometrical Survey, the Geological Survey and the Botanical Survey of India on the other. More importantly, the scientific and technical education received the necessary support and the first three Indian universities were established right at the time of the Indian Mutiny to be followed later by two other universities at Lahore and Allahabad. Telegraph and the railways, too, made their appearance in the middle of this century and assumed an operative network soon. The closing decades of the century are more remarkable, for they heralded the dawn of scientific interests exhibited by

the Indian intellectuals, some of whom made noteworthy contributions in the fields of mathematics, physics and chemistry. Indeed the progress in scientific endeavours in the nineteenth century was in tune with the general advancement of India, for as Majumdar says: 'If we analyse the progress of Indian people during the nineteenth century, it will appear that there was hardly any aspect of life and society which was not deeply affected by the western impact. The nineteenth century was a great dividing line, and these hundred years changed the face of India far more than did the preceding thousand years.'[a]

Trigonometrical Survey

The political necessities and exigencies of the East India Company demanded a thorough geographical knowledge of the country under its occupation. Though Topping and Rennel in the Madras Presidency had conducted a systematic survey work earlier, it was William Lambton, an outstanding geographer and geodesist as he was, who brought in the trigonometrical survey, and his scientific mapping of southern India using geodetic instruments (which included chains, pickets, theodolite and a zenith sector, the last being still preserved in the Victoria Memorial Hall at Calcutta) was to serve as a foundation for a general survey of the whole country. When his results with detailed explanations were published, it was soon realized that 'a survey was proceeding in India that would yield geodetic results of the highest importance to science'. In 1818 came into being the Great Trigonometrical Survey of India. George Everest, who worked as surveyor under Lambton, undertook later the survey of North India and became Surveyor-General of India and Superintendent of the Great Trigonometrical Survey in 1830. As a result of a network of first quality survey work, the Himalayan region was explored, the highest peak in the world was discovered and rightly named after Everest. In 1878, the trigonometrical, topographical and the revenue surveys were clubbed under the title, Survey of India. Colonel Waugh and Major-General Walker were the other two distinguished surveyors of India. To Radhanath Sikdar belongs the honour of the first Indian to have worked with Everest in the survey work and the associated mathematical applications and to have won his master's approbation. In 1864 Radhanath was elected a corresponding member of the Society of Natural History (Bavaria)—a rare distinction conferred by this society on a foreigner (**10**, pp. 507–14).

Geological Survey

The Geological Survey of India came into being in 1851 and was established as a Government Department in 1857. Thomas Oldham, who came to India in 1851 as Superintendent of Geological Survey, was solely

[a] Majumdar (R. C.), X, Pt. II, pp. 95–96.

responsible for a systematic geological work which was, to begin with, confined to investigations of coalfields in the eastern and central India. H. B. Medlicott and the Blanford brothers (W. T. Blanford and H. T. Blanford) were the other noted geologists. Both Oldham and W. T. Blanford worked on the correlation and classification of peninsular formation. The Blanford brothers and Theobald elucidated the origin of the Talchir boulder beds and Godwin-Austen discovered the oldest rocks in the Khasi and Jaintia hills in Assam. Some palaeontological studies were also undertaken by Falconer, Feistmantel, Lydekker adn Pilgrim. In 1875 a first-class medal was awarded to the Geological Survey of India for its exhibits at the *Congress Internationale des Sciences Geographiques* held at Paris. Apart from these investigations, the Geological Survey of India also studied the Indian earthquakes. Bairdsmith of the Bengal Engineers made observations on the general distribution of subterranean disturbing forces in operation throughout India. T. H. Holland discovered the hypersthene-bearing granatoid rocks in the Madras Province. P. N. Bose and P. N. Dutta were the two Indians who occupied covenanted posts and were known for their geological acumen. The former was the first to publish the study of micro-section as an aid to the study of rocks, and the latter was largely responsible for the present location of the Tata Iron and Steel Works at Jamshedpur. P. N. Dutta discovered the vast deposits of manganese ore in the Bhandara and Chindwara river valley (**10**, pp. 523–28).

Botanical Investigations

After the death of Roxburgh, Nathaniel Wallich undertook botanical investigations in Nepal, Assam, Penang, Singapore, etc., and classified his rich collections which became a veritable mine of information for the European botanists of the time. He donated some of his collections to the reputed Linnean Society in England and produced *Plantae Asiaticae Rariores* in 3 volumes with 300 coloured plates in 1832. The botany of the Himalayan region assumed importance and a number of species of plants were collected. The Botanic Garden at Calcutta as well as the one at Saharanpur grew in size, and in the former a herbarium of international repute took shape. The herbarium not only housed almost all the dried plant materials of the whole of the Indian subcontinent, Asia Minor, Europe and Australia but also maintained international exchanges of specimens. George King who became the Superintendent of the Garden in 1871 did great service in reorganizing it on a scientific basis. In 1890, when the present Botanical Survey was established, he was appointed as the first Director of the Survey, and later he became the Director of the famous Royal Botanic Garden at Kew in England. The scientific investigations of the Botanical Survey of India have been largely responsible for the growth on the Indian soil of such exotic plants as cinchona, rubber, tea, potato, coffee, certain fibrous plants, tobacco, etc., of commercial importance (**10**, pp. 514–20).

Meteorology and other Physical Investigations

In the beginning of the nineteenth century, the importance of studies in weather, cyclone, tides, etc., was keenly felt. Some meteorological observations were also made at the coastal towns. The efforts were continued and, between 1865 and 1871, several provincial meteorological organizations came into being and to consolidate their work was established the India Meteorological Department in 1875. Preparation of daily weather charts, issuing cyclone warnings, seismological studies, solar physics, and terrestrial magnetic studies were among the important functions of this department. As early as in 1834 India participated in the global study of the earth's magnetism organized by the Gottingen Magnetic Union to record the simultaneous magnetic observations at 50 stations, of which three were in India. A magnetic observatory was already in existence in 1826 at Colaba in Bombay and was later shifted to Alibag in view of the introduction of the electric traction for the street tram since then, lest the electric current should vitiate the magnetic observations. In 1895 the foundation of the solar physics laboratory was laid at Kodaikanal and it started functioning in 1900. Spectroscopic work, hydrogen content of the solar prominences, spectrum of the night sky, etc., were the important investigations undertaken in the laboratory (**10**, pp. 501–507). As regards geophysics, Basevi and his co-workers observed the gravity anomalies in the Himalayan region, and these were interpreted mathematically by A. Pratt, as a result of which the theory of isostatic compensation emerged.

Indian Museum

The Asiatic Society which continued to play an effective role in encouraging scientific investigations into the natural history of the country gave a lead in the direction of antiquarian studies. This provided the initial stimulus for the Indian archaeology and the Archaeological Survey of India was started in 1860 with Cunningham as the first Surveyor.

The Society had already accumulated a number of materials and curios which included ancient relics, coins, plant specimens and minerals as a result of investigations conducted by the members of the Society, and it was realized that they deserved preservation. Besides, the Society had under its care the government's collection of minerals, fossils and the like under the name of Museum of Economic Geology (1840). Time was ripe for the establishment of a well-planned museum in Calcutta and the initiative taken by the Society resulted in the establishment of the Indian Museum in 1867. The scientific staff of the Indian Museum made valuable contributions to zoology and brought out a number of zoological notes and volumes relating to birds, mammalia, reptiles, mollusca, lepidoptera, fishes and the like (**10**, pp. 528–30).

Scientific and Technical Education

The two institutions which came into being in the last two decades of the eighteenth century, viz. the Calcutta Madrasah (1781) and the Benares

Sanskrit College (1791), sought to encourage only the indigenous system of education including medicine and arithmetic. In 1813, when the East India Company's charter was renewed, a clause was introduced to the effect that a sum of not less than one *lac* of rupees might be spent 'for the introduction and promotion of the knowledge of the sciences among the inhabitants of the British territories in India'. In 1817 was established at Calcutta the *Mahāvidyālaya*, 'Seminary for the instructions of the sons of the Hindus in the European and Asiatic languages and sciences', by some enlightened gentlemen including David Hare and Raja Rammohan Roy. The need for educating the Indian students in modern science and in the medium of English was brought home to the British Government in no unmistakable terms by Rammohan Roy. William Bentinck, Macaulay and Dalhousie were among the principal administrators who contributed to the growth and spread of scientific education. The Wood's Despatch of 1854 made possible the creation of the universities on the model of the London University, and with the establishment of the three universities at Calcutta, Bombay and Madras in 1857, the scientific and technical education in India assumed a definite form. The universities, however, were only the affiliating and examining bodies. As the administrative exigencies of the government demanded the employment of local doctors and engineers, some engineering and medical institutions were also established, and instructions were imparted at two levels in colleges and schools. The notable institutions were the engineering colleges at Sibpur (Calcutta), Poona and Roorkee; medical colleges at Calcutta, Bombay and Madras, Victoria Jubilee Technical Institute at Bombay, School of Industrial Arts at Madras, agricultural and veterinary schools at a number of places in the three presidencies. Towards the close of the nineteenth century there were about 170 colleges including four medical and an even number of engineering colleges, and a number of technical schools affiliated to the five universities, which were offering courses in scientific subjects, medicine, engineering, agriculture and certain crafts (**10**, pp. 541–56).

A remarkable feature of the last two decades of the nineteenth century was that the Indian bright students came forward to take up independent investigations even in mathematical and physical sciences. Asutosh Mukherji, J. C. Bose and P. C. Rây were well known for researches in mathematics, physics and chemistry respectively (**10**, pp. 556–60). In particular, J. C. Bose devised his own experiments with great ingenuity and displayed a new spirit of inquiry. P. C. Rây became the founder of what has come to be known as the Indian Chemical School and leader of the Indian chemical industry. What is more, the importance of modern science as a new and purposeful way of understanding was increasingly realized, and local attempts were initiated for the promotion of scientific investigations and diffusion of scientific knowledge. The Indian Association for the Cultivation of Science was established by Mahendra Lal Sircar in 1876, through public endowments, with the object of promoting scientific interests. The physical investigations conducted by C. V. Raman later at

this Association enabled him to have the distinct honour of being the first Indian to receive the Nobel Prize for Physics.

At the end of the nineteenth century the emergent picture revealed the growing interest in modern science evinced by the Indian students, the government's keen desire to reform the universities enabling them to take up teaching as well as research and an enlargement of the area of involvement of the government, educationists, industrialists and philanthropists in laying a solid foundation for the growth of modern science and technology in India.

CHRONOLOGICAL TABLE

Date	Scientific and Technological Developments	Remarks
c. 150000–25000 B.C.	*Early Palaeolithic or Early Stone Age*:	
	Chopper-chopping tool culture.	The Panjab[a]
	Hand-axe culture.	The Panjab, Peninsular India, barring extreme south India[a]
c. 25000–5000 B.C.	*Middle Palaeolithic or the Middle Stone Age*: predominance of flake tools, scrappers, borers, points, etc.	do
c. 5000–3000 B.C.	*Mesolithic or the Late Stone Age*: predominance of microliths, flakes, blades, lunates, borers, scrappers, chisels, trapezoids, triangles, drills, etc.	Gujerat, Maharashtra,[a] Madhya Pradesh, Mysore, Tinnevelly, (Tamilnadu), Birbanpur (West Bengal), etc.
c. 3500 B.C.	*Neolithic Age*.	Baluchistan
c. 2300–1750 B.C.	*Flourishing Period of Harappan Culture*: copper-bronze technology, *cire perdue* process; wheel-made decorated and glazed pottery; settled agriculture, wheat and barley; domestication of animals; drainage and public bath, burnt brick and mortar constructions; grid system of town planning; spinning and weaving; measurement and computational techniques.	Sind, Baluchistan, the Panjab, Rajaputana and Saurashtra; influenced later settlements also
c. 2000 B.C.	Some *Neolithic* settlements; agriculture; cave-drawings and paintings, depicting mainly animals; hand-made and later wheel-made pottery.	Andhra, Karnatak, Kashmir and Bengal regions
c. 1800 B.C.	Some *Chalcolithic* settlements; use of copper tools; *Black-and-Red ware*; *Malwa ware* and *Jorwe ware*; spouted vessels.	Saurashtra, Rajaputana, central, southern and eastern India

[a] Sankalia (4), pp. xxi–xxii.

CHRONOLOGICAL TABLE—*contd.*

Date	Scientific and Technological Developments	Remarks
c. 1700–1000 B.C.	*Ochre-coloured ware*: copper-hoards.	Closed casting of the alloyed and unalloyed metal
c. 1500 B.C.	The *Ṛgveda*: concept of natural law (*ṛta*); monistic idea concerning water; 'lunar mansions' or the *nakṣatra* system of marking the ecliptic, beginnings of calendar system; knowledge of diseases and cure; agricultural practices, use of plough, wheat and barley; fermentation methods; use of horse of superior breed.	The Panjab and Kashmir regions; earliest literary composition of its type
c. 1000 B.C.	The *Yajurveda*: the whole series of 27 or 28 *nakṣatras* headed by *Kṛttikā*, number-names on the decimal scale up to 10^{12}; agricultural practices, mentions rice.	Western U.P.; mentions rice
c. 1000 B.C.	The *Atharvaveda*: astronomical knowledge; details of *nakṣatras*, method of *intercalation*; more detailed medical knowledge and associated practices; lists of different plants and animals.	Some parts of the *Atharvaveda* seem to be earlier Concept of *prāṇa* as the sustainer of life
c. 1000–600 B.C.	The *Brāhmaṇas*, *Āraṇyakas* and *Upaniṣads*: astronomical ideas, cosmic cycle; beginnings of mathematical series (both A.P. and G.P.); more physiological and anatomical knowledge; doctrine of the *pañcabhūtas*; further elucidation of the world of the living and non-living.	The idea of cosmic cycle possibly influenced the Greek thinking later
	Painted-Grey ware: in association with iron.	A *de luxe* pottery mainly in northen and north-western parts of India
	Production and use of iron.	In small open-hearth furnaces
	Agricultural practices—rotation fallowing method to increase the soil fertility.	
c. sixth–fifth cent. B.C.	*Northern Black-Polished ware*, associated with the use of iron: making of steel.	Mainly in eastern parts; later spread to central and other parts of India
	Glass objects at Taxila.	Bhir mound at Taxila
	Codification of medical knowledge into the *Āyurveda*:	
	Vedāṅga Jyotiṣa: five-year cycle; further elaboration of calendarical science.	*Nakṣatra* system continued to be the basis

CHRONOLOGICAL TABLE—*contd.*

Date	Scientific and Technological Developments	Remarks
	Śulba-sūtras: beginnings of geometry; anticipation of the Pythagorean theorem; development of the knowledge of the irrational numbers.	As aid to construction of sacrificial altars
	Early ideas of the Vaiśeṣika; *Sāṃkhya* and the *Mīmāṃsā*; of the Bauddha, Jaina and the Cārvāka; physical concepts: atomism, space, time, motion and sound.	As part of the respective religio-philosophical position
Fourth cent. B.C. to fourth cent. A.D.	The Āyurvedic treatises—the *Caraka* and the *Suśruta Saṃhitās*: the *tridoṣa* theory; physiology; anatomy; pathology; therapeutics; surgical practices.	Emphasis on herbal medicine; skill in rhinoplasty, laparotomy and lithotomy
	Development of the orthodox philosophical *sūtras*; the Jaina, the Bauddha schools; extension of the doctrine of five elements, space, time and sound.	Respective epistemological positions defined
	The *Arthaśāstra* of Kauṭilya: mining, metal-working, agriculture and irrigation.	
	Bhagavatī-sūtra; *Tattvārthādhigama-sūtra* of Umāsvātī: atomism, classification of living and non-living.	
	Recasting of astronomical ideas; adoption of the zodiacal system; knowledge of the motion of planets.	Possibly some Babylonian and Greek influences
	Progress in mathematics; permutations and combinations—*meruprastrāra* and the early binomial ideas.	Piṅgala's *Chandaḥ-sūtra*
	Increased and widespread use of iron; constructtion of the Sudarśana Lake	Use of bellows for extracting and forging iron
	Glass objects at a number of places.	Foreign influences, particularly Roman, at Taxila (Sirkap) and Arikamedu (Tamilnadu)
Fifth cent. A.D.	*Nyāyabhāṣya* of Vātsyāyana—atomic ideas further extended; views on vision and propagation of sound; impetus theory; classification of animals and plants.	

CHRONOLOGICAL TABLE—*contd.*

Date	Scientific and Technological Developments	Remarks
	Padārthadharmasaṃgraha of Praśastapāda; atomism, space, time, motion, sound.	Also known as *Praśastapādabhāṣya*; though a *bhāṣya* on the Vaiśeṣika categories, an independent work
Fifth cent. A.D.	*Āryabhaṭīya*: theory of the rotation of the earth, epicyclic theory for the planetary motions; values of π and sines; alphabetical system of expressing decimal place-value notation; extraction of square and cube roots; indeterminate equation of the first order.	Growth of the Indian decimal place-value system
	Metal-working; art of jewellery; Iron Pillar now at Delhi.	Made of wrought iron (99·72%)
	Copper statue of the Buddha from Sultanganj in Bihar (now in Birmingham Museum).	Cast in two layers
	Sophisticated ceramic ware.	Particularly on the Indo-Gangetic plains
Sixth cent. A.D.	*Pañcasiddhāntikā* of Varāhamihira—the five *siddhāntas*: *Saura*, *Pauliśa*, *Romaka*, *Brāhma* and *Paitāmaha*; concept of *mahāyuga* (4,320,000 years); notion of the libration of the equinoxes in the *Sūryasiddhānta*.	The *Sūryasiddhānta* considered as the best and the most accurate
	Bṛhat Saṃhitā of Varāhamihira—a number of chemical processes; plant and animal classifications.	Encyclopaedic work
	Amarakośa: classification and synonyms of plants and animals, minerals and metals.	Lexicon
	Buddhist logic and Jaina views.	Problem of matter elucidated
Seventh–eighth cent. A.D.	Brahmagupta—astronomer and mathematician: *Brāhmasphuṭasiddhānta* and *Khaṇḍakhādyaka*; lemma for solution of the indeterminate equation of the second order; formula for the sum of *n* terms of Arithmetic progression; rules for the volume of a prism; area of the cyclic quadrilateral, etc.	Both translated into Arabic in the eighth cent. A.D., under the titles *Sindhind* and *Arkand*

CHRONOLOGICAL TABLE—*contd.*

Date	Scientific and Technological Developments	Remarks
	Nyāya-vārtika of Udyotakara; further elucidation of atomic views.	
	Rugviniścaya of Mādhava; emphasis on diagnostic methods.	Also called *Mādhava-nidāna*; translated into Arabic under the title *Badon*
	Use of the Persian water-wheel (*araghaṭṭa*)	
	Aṣṭāṅgahṛdaya of Vāgbhaṭa; an authoritative compilation of the Āyurvedic knowledge based on the earlier works.	Rendered into Arabic under the title *Astankar*
Ninth–tenth cent. A.D.	*Gaṇitasārasaṃgraha* of Mahāvīra—operations involving zero and summation of *n* terms of Geometrical Progression.	Flourished in Mysore
	Kṛṣi-Parāśara and *Vṛkṣāyurveda*.	Manuals on agriculture and botany
	Alchemical practices; *Rasahṛdaya* of Govinda Bhagavat.	As part of tantrik practice
	Siddha system of medicine.	Mostly followed in Tamilnadu; use of mainly mineral medicines
	Muñjāla's elucidation of the precession of equinoxes.	As against the earlier libration concept
Eleventh–twelfth cent. A.D.	Śrīdhara's method of solving quadratic equations.	
	Siddhāntaśiromaṇi of Bhāskara II: astronomical and mathematical work in four parts; *cakravāla* method for rational integral solutions of the indeterminate equation of the second order; geometric proof of the Pythagorean theorem; root idea of differential calculus; further elaboration of epicyclic-eccentric theories for planetary motions; analysis of the motion of the sun by considering longitudinal changes.	Influenced later astronomers and mathematicians; a number of commentaries followed; represents the height of Indian astronomy and mathematics
	Mānasollāsa of Somadeva; alchemical ideas; iron-casting; perfumery.	Encyclopaedic work
	Knowledge of paper-making.	Derived possibly from Nepal and Arabia

CHRONOLOGICAL TABLE—*contd.*

Date	Scientific and Technological Developments	Remarks
	Unāni Tibb.	Incorporation of Persian, Arabic medical and Āyurvedic knowledge from Central Asia
	Metal stirrup; introduction of paper.	
Thirteenth-fifteenth cent. A.D.	*Śāraṅgdhara Saṃhitā*: opium in its materia medica, urine and pulse examination for diagnostic purpose.	Foreign influences
	Rasaśāstra texts: *Rasārṇava*, *Rasaratnākara*; *Rasaratnasamuccaya*, etc.; classification of alchemical and iatrochemical substances, details of experimental techniques.	Skill in complex chemical processes
	Nārāyaṇa Paṇḍita: further refinement of arithmetic and algebraic operations.	
	Parameśvara, a prolific commentator on earlier astronomical and mathematical works.	Belonged to Kerala family of astronomers
	Nīlakaṇṭha Somasutvan: elucidation of astronomical ideas.	Of the *Āryabhaṭīya* school
	Pyrotechnics.	Production centres in the south
c. sixteenth cent. A.D.	Gaṇeśa Daivajña, astronomical and mathematical commentator; Divākara family of astronomers and mathematicians.	Maharashtra school
	More *Rasaśāstra* texts; use of mercurial and non-mercurial compositions as internal medicine becomes widespread.	Iatro-chemistry became established
	Bhāvaprakāśa: extensive materia medica; treatment of syphilis.	
	Gunpowder and guns.	Largely used during the Mughal period
	'*Āin-i-Akbarī*: astronomical ideas; crafts; agriculture and animal husbandry; perfumery; pyrotechnics.	
	Advent of the Portuguese physician Garcia da Orta, introduction of new economic plants.	Publication of Garcia's *Colloquies* (1565)

CHRONOLOGICAL TABLE—*contd.*

Date	Scientific and Technological Developments	Remarks
c. seventeenth cent. A.D.	*Tuzuk-i-Jahangiri*: study of animals and plants.	
	Advent of the Dutch, French and the British.	Establishment of 'factories' for commercial transactions; study of Indian flora
	Publication of *Hortus Malabaricus* of Heindric Van Rheede (1686–1703).	In 12 volumes with illustrations; at Amsterdam
Eighteenth cent. A.D.	Synchronization of Arabic astronomical and mathematical knowledge with that of India.	
1723–27	Construction of Jantar Mantars at Delhi, Ujjain, Mathura, Banaras and Jaipur, by Maharaja Sawai Jai Singh II.	Huge masonry astronomical instruments
	Samrāṭ Siddhānta of Jagannātha.	Translation of the Arabic version of Ptolemy's *Almagest*
	Rekhāgaṇita of Jagannātha.	Translation of the Arabic version of Euclid's *The Elements*
1737	d'Anville's first map of south India and his map of India, *carte de l'Inde.*	Based on the knowledge of the Marāgha school of astronomy and Jesuit sources
c. 1755	Botanical investigations of Koenig in south India.	The collections sent to the University of Lund in Sweden
1761	Survey work of Plainstead on the coasts of Chittagong.	
1764	Ganges river course surveyed by Rennell.	The British East India Company's organized survey work
1781	Madrasah at Calcutta.	Established on the initiative of Warren Hastings
1783	First *Map of Hindoostan* by Rennell.	
1784	*The Asiatic Society* founded at Calcutta.	William Jones, the Founder-President
1785	First presentation of a paper in Persian by a Mohammedan scholar entitled 'The Care of the Elephantiasis and other Disorders of the Blood'.	Translated and presented by William Jones himself

CHRONOLOGICAL TABLE—*contd.*

Date	Scientific and Technological Developments	Remarks
1787	Royal Botanic Garden at Sibpur (Calcutta).	Robert Kyd, first Honorary Superintendent
1791	*Saṃskṛta Pāṭhaśālā* at Banaras.	By the efforts of Jonathan Duncan
1792	Madras Observatory established.	By Michael Topping
1793–94	William Roxburgh as the Superintendent of the Royal Botanic Garden.	Commencement of systematic botanical studies
1794	Survey School at Madras.	Beginnings of trigonometrical survey
1795	Commencement of the Geodetic work of Lambton.	In the Peninsula
1795	Commencement of the publication of the *Flora Indica.*	In three volumes, 1795, 1802 and 1819
Nineteenth cent. A.D.		
1800	Establishment of the Trigonometrical Survey Department at Madras.	
1813	Renewal of East India Company's Charter—introduction of a clause for spending one *lac* of rupees per year for the promotion of the knowledge of sciences among the people of India.	Beginnings of British interests in educating the Indians in science
1814	Nathaniel Wallich as the Superintendent of the Botanic Garden.	His botanic collections sent to the European centres of botanical studies
1815	General map of southern region by Lambton.	Measurement of the largest meridional arc
1817	Establishment of *Mahāvidyālaya* (Hindu College) at Calcutta. Raja Rammohan Roy's primary role in the introduction of the study of western sciences in India.	Public patronage of English education
1818	Formation of the Great Trigonometrical Survey at Calcutta.	
1822	Preparation of an Atlas of India on the quarter inch scale.	

CHRONOLOGICAL TABLE—*contd.*

Date	Scientific and Technological Developments	Remarks
1830	George Everest as the Superintendent of the Great Trigonometrical Survey.	
1832	*The Journal of the Asiatic Society of Bengal*: in the first volume James Prinsep's observation of the transit of mercury on the 5th May, 1832, made with a four feet achromatic telescope of 4 inch aperture, mounted equatorially and provided with a delicate wire micrometer.	Its forerunners: (i) *Asiatick Researches* and (ii) *Gleanings in Science*
1835	Calcutta Medical College.	
1843	Medical School at Madras.	
1845	The Grant Medical School at Bombay.	
1847	Engineering Institution at Roorkee.	Later became Thomason Engineering College
1851	Establishment of the Geological Survey of India.	Thomas Oldham's efforts
1851	The first telegraph line between Calcutta and Diamond Harbour.	By William O'Shaughnessy
1853	The first railway line laid.	Near Bombay
1854	Charles Wood's Despatch for the creation of the universities.	On the model of the London University
	Engineering School at Poona.	
1856	Engineering College at Sibpur (Calcutta).	
1857	Establishment of the first three universities at Calcutta, Bombay and Madras.	Only affiliating and examining bodies
1859	Civil Engineering College at Madras.	
	Establishment of Archaeological Survey of India.	Cunningham as the Archaeological Surveyor
1867	Indian Museum came into being at Calcutta.	Galleries thrown open to the public only in 1878
1875	Establishment of India Meteorological Department.	
1876	Foundation of the Indian Association for the Cultivation of Science.	By Mahendra Lal Sircar through public endowments
1881	Publication of the first mathematical paper of Asutosh Mukherji.	In the *Messenger of Mathematics*

CHRONOLOGICAL TABLE—*concld.*

Date	Scientific and Technological Developments	Remarks
1884	Centenary of the Asiatic Society of Bengal.	In its publications over 500 papers in mathematical and physical sciences, 560 in zoology, 320 in botany were published (1788–1882)
1890	Imperial Bacteriological Laboratory at Poona.	Later shifted to Mukteswar (1893)
	Botanical Survey of India formed.	George King, the first Director
1895	Foundation of the Solar Physics Laboratory at Kodaikanal.	Started working from 1900
	J. C. Bose's first scientific paper on the polarization of electric waves by double refraction.	In *JASB*
1896	Plague Research Laboratory at Bombay with Haffkine as its Director.	In 1906, the name was changed to the Haffkine Institute
	P. C. Rây's work on mercurous compounds.	Preliminary note appeared in *JASB*
	Recommendation of the Royal Agricultural Commission emphasizing research on agriculture.	Establishment of Imperial Agricultural Research Institute at Pusa (Bihar) in 1903
1897	J. C. Bose's lecture at the Royal Institute, London, with his own apparatus.	
1900	J. C. Bose's paper, 'On the Generality of the Molecular Phenomena produced by Electricity on Living and Non-living Substances'.	Read at the International Congress in Physics, Paris
	P. C. Rây's analyses of a number of rare Indian minerals to discover in them some of the missing elements in Mendeleef's Periodic Table.	Published in the *Memoirs of the Geological Survey of India*

ABBREVIATIONS

A. PERIODICALS, SERIAL PUBLICATIONS AND SOME SELECTED ORGANIZATIONS

AI	Ancient India
AIHS	Archives Internationales d'Histoire des Sciences
AP	Asian Perspectives
AR	Asiatick Researches
ASB	Asiatic Society of Bengal
BMFNISI	Biographical Memoirs of Fellows of the National Institute of Sciences of India
BCMS	Bulletin of the Calcutta Mathematical Society
BI	Bibliotheca Indica
BLIA	Bulletin of the London Institute of Archaeology
BNISI	Bulletin of the National Institute of Sciences of India
BSOS	Bulletin of the School of Oriental Studies
CB	Chronica Botanica
CF	Cultural Forum
CGPO	Calcutta G.P.O. Centenary Volume
CHI	Cambridge History of India
CMJ	Calcutta Medical Journal
CR	Calcutta Review
CRASB	Centenary Review of the Asiatic Society of Bengal
CS	Current Science
CULHI	Cultural Heritage of India
EB	Encyclopaedia Britannica
GA	Gollingische gelehrte Arzeigen
GI	Gazetteer of India
GSI	Geological Survey of India
HOS	Harvard Oriental Series
HKDVS	Historisk-filosofiske skrifter u.a.d. Kongelige Danske Videnskabernes Selskab

IC	Islamic Culture
ICAR	Indian Council of Agricultural Research
IF	Indian Forester
IHQ	Indian Historical Quarterly
IJHS	Indian Journal of History of Science
IJMG	Indian Journal of Meteorology and Geophysics
IMB	Indian Museum Bulletin
IS	Indische Studien
ISCA	Indian Science Congress Association
JA	Journal Asiatique
JAOS	Journal of the American Oriental Society
JASB	Journal of the Asiatic Society of Bengal
JBRS	Journal of the Bihar Research Society
JBBRAS	Journal of the Bombay Branch of the Royal Asiatic Society
JBNHS	Journal of the Bombay Natural History Society
JDL/CU	Journal of the Department of Letters, Calcutta University
JESHO	Journal of the Economic and Social History of the Orient
JGRS	Journal of Gujarat Research Society
JMG	Journal of Meteorology and Geophysics
JMGA	Journal of the Madras Geological Association
JMSUB	Journal of the Maharaja Sayajirao University of Baroda (Humanities)
JNES	Journal of the Near Eastern Studies
JOI	Journal of the Oriental Institute
JORIM	Journal of the Oriental Research Institute, Madras
JPSI	Journal of the Palaeontological Society of India
JRAI	Journal of the Royal Anthropological Institute
JRAS	Journal of the Royal Asiatic Society
JTI	Journal of the Textile Institute
JUG	Journal of the University of Gauhati
JZSI	Journal of the Zoological Society of India
KB	Kew Bulletin
MASB	Memoirs of the Asiatic Society of Bengal
MASI	Memoirs of the Archaeological Survey of India
MGSI	Memoirs of the Geological Survey of India
MIM	Memoirs of the Indian Museum
MJLS	Madras Journal of Literature and Science
NGWG/PH	Nachrichten von der königlichen Gesellschaft der Wissenschaften zu Göttingen (*Phil-hist. Klasse*)
NISI	National Institute of Sciences of India

CS. Vi	——— Vimānasthāna
CS. Śā	——— Śārīrasthāna
CS. In	——— Indriyasthāna
CS. Ci	——— Cikitsāsthāna
CS. Ka	——— Kalpasthāna
CS. Si	——— Siddhisthāna
Chand. Sū	Chandaḥ-sūtra of Piṅgala
Ci.Sam.C	Cikitsā-saṃgraha of Cakradatta
Chānd. Pr	Chāndogya Prapāṭhaka
Chānd. Up	Chāndogya Upaniṣad
Ci.Sam.N	Cikitsā-saṃgraha of Nakula
Ci.Sam.V	Cikitsā-saṃgraha of Vaṅgasena
Cunnak	Cunnakandam
DS	Dhammasaṅgāni
DM	Dhātumañjarī
DRM	Dhāturatnamālā
Dhī	Dhīkoṭi
DN	Dīgha Nikāya
Div	Divyāvadāna
Dr. Saṃ	Dravyasaṃgraha
Dṛg. G	Dṛggaṇita
Fir. Ḥik	Firdausúl-Ḥikmat
F	Fihrist
GTr	Gaṇakataraṅgiṇī
GK	Gaṇitakaumudī
GAK	Gaṇitāmṛta-kūpikā
GS	Gaṇitasāra
GSS	Gaṇita-sāra-saṃgraha
GTCi	Gaṇitatattva-cintāmaṇi
GT	Gaṇitatilaka
GYBh	Gaṇitayuktibhāṣā
Gar. Up	Garbha Upaniṣad
Ghun. Ḥi	Ghunyatu'l-Hussāb fī'Ilmi'l Ḥisāb
Gil. Ms	Gilgit Manuscript
Gil. Bv	——— Bhaiṣajyavastu
Gil. Cv	——— Cīvaravastu
Gol. D	Goladīpikā of Parameśvara
Gol. S	Golasāra
Gop. Br	Gopatha Brāhmaṇa
GL	Grahalāghava
GM	Grahaṇamaṇḍana of Parameśvara
GAP	Gūḍhārtha-prakāśikā of Raṅganātha

HS	Hārīta Saṃhitā
HV	Harivaṃśa
Hst. Āyur	Hastyāyurveda or Pālakāpya Saṃhitā
HLS	Hayalīlāvatīnāma-saṃgraha of Jayadatta
Ikh. Q	Ikhtiyarati-Qasimi or Dasturil-Atbba
Iks. Aẓ	Iksiri-A'ẓam
JDP	Jambūdvīpaprajñapti
JDS	Jambūdvīpasamāsa
Jami. Shi	Jami'ush-Shifaiya
KLV	Kalpalatāvatāra of Kṛṣṇa Daivajña
KS	Kāmasūtra of Vātsyāyana
KCMT	Kākacaṇḍeśvarīmatatantra
KG	Kaṅkālī Grantha of Narasiṃha Śāstrī
KR	Kaṇādarahasya of Śaṅkara Miśra
KKu	Karaṇakutūhala
KP	Karaṇapaddhati
KD	Karmadīpikā
Kās. S	Kāśyapa Saṃhitā
Kśl	Kātyāyana-śulba-sūtra
Kāṭh. S	Kāṭhaka Saṃhitā
Kauṣ. Ār	Kauṣītaki Āraṇyaka
Kauṣ. Br	Kauṣītaki Brāhmaṇa
Kauṣ. Sū	Kauṣītaki-sūtra
Kauṣ. Up	Kauṣītaki Upaniṣad
KCi	Kautuka Cintāmaṇi of Gajapati Pratāparudradeva
Kha. Taj	Khayrut-Tajárib
Khul. Hi	Khulāṣatu'l-Ḥisāb of Bahā'u'ddīn al-'Āmulī
Khul. Taj	Khulastu't-Tajárib
KK	Khaṇḍakhādyaka
KKV	Khaṇḍakhādyaka-vivaraṇa
KV	Kiraṇāvalī of Udayana
KA. St. Mut	Kitāb Arshīmīdas fi'd-Dawā 'iri'l-Mutamāssah
KFak. Jab	Kitāb al-Fakhrī fī'l (Ḥisāb) Jabr-i-wa'l Muqābilah
KIst. MWaq	al-Kitāb fī Istikhraji'l (Autār) ... Munḥani'l-Wāqi'fihā
KKUst	Kitābu'l-Kurah Wal-Usṭuwānah
Kṛ. P	Kṛṣi-Parāśara
Lbhv	Laghubaṅgīvibhaṅgī
LBh	Laghubhāskarīya
LBh. V	Laghubhāskarīya-vyākhyā
LJ	Laghujātaka
LMā	Laghumānasa

LMā. V	Laghumānasa-vyākhyā
LTCi	Laghutithi cintāmaṇi
LVSi	Laghu-Vaśiṣṭha-siddhānta
Lāṭ. Śr. Sū	Lāṭyāyana Śrautasūtra
Lī	Līlāvatī of Bhāskara II
Lī. V	Līlāvatī-vyākhyā of Parameśvara
LP	Lohapaddhati of Sureśvara
Ma. Shi. Sik	Ma'danush-Shifāi-Sikandari
MNi	Mādhava Nidāna or Rugviniścaya
MK	Madhukośa by Vijayarakṣita
MB	Mahābhārata
MBh	Mahābhāskarīya
MBh. V	Mahābhāskarīya-bhāṣya
MSi	Mahāsiddhānta
Mait. S	Maitrāyaṇī Saṃhitā
Mait. Up	Maitrāyaṇī Upaniṣad
Maj. Di	Majmuai-Diyaiyya by Diya Muhammad
Maj. Sha	Majmuai-Shamaiyya
Mā. Sā	Mānasāra
Mā. ull	Mānasollāsa or Abhilaṣitārthacintāmaṇi
Mśl	Mānava-śulba-sūtra
MS	Manu Saṃhitā or Manu Smṛti
Maq. Arsh. Tak. Dā	Maqālah-i-Arshīmīdas fī Taksīri'd-Dā'rah of Nāṣīr-al-dīn aṭ-Ṭūsī
Maq. Jabr	Maqālah fī'l-Jabr-i of al-Khayyāmī
M	Marīci
Māt. Bh. T	Mātṛkābheda Tantra
MP	Matsya Purāṇa
Mi. Bh	Mitabhāṣiṇī of Raṅganātha
Megh	Meghadūta of Kālidāsa
Mṛcch	Mṛcchakaṭika
MṛPŚ	Mṛga-pakṣī-śāstra
Muṇḍ. Up	Muṇḍaka Upaniṣad
Nāḍī. P	Nāḍī-parīkṣā
Nāḍī. Vi	Nāḍī-vijñāna
Nār. Smṛ	Nārada Smṛti
Navāṅk	Navāṅkura
Ni. Sū	Nidānasūtra
NBh	Nyāyabhāṣya of Vātsyāyana
NB	Nyāya-bindu
NK	Nyāya-kandalī
NL	Nyāya-līlāvatī of Vallabha
NM	Nyāya-mañjarī of Jayanta Bhaṭṭa
NMk	Nyāya-muktāvalī

NP	Nyāya-praveśa
NSā	Nyāyasāra of Bhāsarvajña
NSi. D	Nyāyasiddhāntadīpa of Śaśadhara
NS	Nyāya-sūtra of Gautama
NV	Nyāya-vārttika of Udyotakara
NVTT	Nyāya-vārttika-tātparyaṭīkā of Vācaspati Miśra
NAv	Nyāyāvatāra
PTN	Padārtha-tattvānirūpaṇa of Raghunātha Śiromaṇi
PiSi	Pitāmaha-siddhānta or Paitāmaha-siddhānta
PSi	Pañca-siddhāntikā
Pañc. Br	Pañcaviṃśa Brāhmaṇa
Pār. S	Pārada Saṃhitā
Pār. Y	Pāradayoga
Pāṭī	Pāṭīgaṇita of Śrīdhara
Pr. Sm	Pramāṇasamuccaya
PBh	Praśastapāda Bhāṣya or Padārthadharma-saṃgraha
Praś. Up	Praśna Upaniṣad
PuSi	Puliśa (or Pauliśa)-siddhānta
Qānūn	Qānūn fī-l-ṭibb by ibn Sīnā
Qānūn. Ma	al-Qānūn al-Ma'sūdī of al-Bīrūnī
Rāj. Mā	Rājamārtaṇḍa by Bhojarāja
Rājt	Rājataraṅgiṇī
Rām	Rāmāyaṇa
RBhK	Rasabheṣajakalpa of Sūrya Paṇḍita
RdCi	Rasendra-cintāmaṇi of Rāma Chandra
Rd. Cū	Rasendra-cūḍāmaṇi of Somadeva
Rd. Sā	Rasendrasāra
Rd. SS	Rasendrasāra-saṃgraha of Gopālakṛṣṇa Kavirāj
RHṛ	Rasahṛdaya of Govinda Bhāgavat
RK	Rasakaumudī of Jñāna Candra
RM	Rasamaṅgala
RMṛ. or *RAm*	Rasāmṛta of Rāmeśvara
RMu	Rasamuktāvalī of Devanātha
RPd	Rasapaddhati of Bindu Paṇḍita
RPr	Rasapradīpa
RPS	Rasaprakāśa-sudhākara of Yaśodhara
RRL	Rasarājalakṣmī of Rāmeśvara Bhaṭṭa
RRM	Rasaratnamālā of Narasiṃha Kavirāja
RRS	Rasaratna-samuccaya of Vāgbhaṭa
Rṇv	Rasārṇava
Rṇv. K.	Rasārṇavakalpa in Rudrayāmala
RRNa	Rasaratnākara of Nāgārjuna
RRNi	Rasaratnākara of Nityanātha

RSK	Rasasaṅketa-kālika of Cāmuṇḍā
RS	Rasasāra of Govindācārya
RAv	Rasāvatāra
RvD	Raseśvara-darśana by Mādhavācārya
RG	Rekhāgaṇita
ṚV	Ṛgveda
Ṛts	Ṛtusaṃhāra of Kālidāsa
RSi	Romaka-siddhānta
RkS	Rukmiṇīsvayamvara
SRM	Sadratnamālā
Ṣd. S	Ṣaḍdarśanasamuccaya
Sāk. Si	Sākalya-siddhānta
Śāli. S	Śālihotra Saṃhitā
Śāli-SS	Śālihotrasārasamuccaya by Kalhaṇa
Sam. Si	Samrāṭ-siddhānta
SV	Sāmaveda
SK	Sāṃkhya Kārikā
SPBh	Sāṃkhyapravacana-bhāṣya
Sāṃkh. Ār	Sāṃkhyāyana Āraṇyaka
Samav. Sū	Samavāyāṅga-sūtra
SN	Saṃyukta Nikāya
SP	Saptapadārthī of Śivāditya
Śārṅg. P	Śārṅgadhara-paddhati
Śārṅg. S	Śārṅgadhara Saṃhitā
Śat. Br	Śatapatha Brāhmaṇa
Sau. PBh	Sauraprakāśa-bhāṣya
Sau. PG	Sauraprakāśa-gaṇita
Sau. Bh	Saurabhāṣya
Sham	ash-Shamsīyah of Hasan an-Nīshāpūrī
Sh. Khul. Hi	Sharh Khulāṣatu'l-Ḥisāb of Luṭfu'llāh Muhandis
Sh. TUH. Hi	Sharh Taḥrīr-u-Uṣūli'l-Handasah Wa'l-Ḥisāb of Mīr Hāshim b. Qāsim al-Ḥusainī
Sh. Uql	Sharh Uqlidas by Aḥmad b. 'Umar al-Karābīsī
Sh. Sham	Sharhu'sh-Shamsīyah of Abū Isḥāq b. 'Abdu'llāh
Si. D	Siddhānta-darpaṇa
Si. Cū	Siddhānta-cūḍāmaṇi
Si. Di	Siddhānta-dīpikā
Si. Śe	Siddhānta-śekhara
Si. Śi	Siddhānta-śiromaṇi
Si. Śi. V	Siddhānta-śiromaṇi-vyākhyā
Si. Su	Siddhānta-sundara
Si. TV	Siddhānta-tattva-viveka
SY	Siddhayoga by Vṛnda Kunda
Si. R	Siddhānta-rahasya
Si. SBh	Siddhānta-sārvabhauma

ŚR	Śilparatna
Śi. Dh. Vṛ	Śiṣyadhīvṛddhida
Śl. V	Ślokavārttika of Kumārila
So. Ni	Soḍhalanighaṇtu
So. Si	Soma-siddhānta
Sthā. Sū	Sthānāṅga-sūtra
ŚN	Śukranīti
Sū. Pr	Sūryaprajñapti
Sū. Si	Sūrya-siddhānta
Sū. Si. V	Sūryasiddhānta-vivaraṇa
SS	Suśruta Saṃhitā
SS. Sū	——— Sūtrasthāna
SS. Ni	——— Nidānasthāna
SS. Ci	——— Cikitsāsthāna
SS. Ka	——— Kalpasthāna
SS. Utt	——— Uttaratantra
ST	Suvarṇatantra
SVM	Syadvādamañjarī
Tah. Uq	Taḥrīr-u-Uqlidas of Nāṣīr-al-dīn aṭ-Ṭūsī
Taitt. Ār	Taittirīya Āraṇyaka
Taitt. Br	Taittirīya Brāhmaṇa
Taitt. S	Taittirīya Saṃhitā
Taitt. Up	Taittirīya Upaniṣad
Tál. Sha	Tálifi-Sharifi
TS	Tantrasaṃgraha
Ta'rīkh. H	Ta'rīkh al-Hind
TRD	Tarka-rahasya-dīpikā of Guṇaratna
TC	Tattvacintāmaṇi of Gaṅgeśa
TSū. Bh	Tattvārthādhigama-sūtrabhāṣya (Umāsvātī)
Tib. Firoz	Tibbe-Firozshahi
Tib. Shi	Tibbe-Shihabi
Tib. Aur	Tibbi-Aurangzebi
Tib. Shi. Mah	Tibbe-Shifai-Mahmudī
Tib. Shi. Kh	Tibbi-Shifaul-Khani
TP	Tithipatra of Makaranda
Triś	Triśatikā
Tuḥ. 'Alam	Tuḥfa-'Alam Sháhi
UV	Upavanavinoda
Umd. Rā	Umdatu'r-Rā'id by Aḥmad b. Thābit
Uttar. Sū	Uttarādhyāyana-sūtra
UHi	'Uyūn'l Ḥisāb by Zainu'l 'Ābidīn
VS	Vaiśeṣika-sūtra
VU	Vaiśeṣika Upaskāra

Vāj. S	Vājasaneyī Saṃhitā
Vci. S	Vājīcikitsā-saṃgraha
VK	Vākyakaraṇa of Parameśvara
Va. Si	Vaśiṣṭha-siddhānta
Vā. V	Vāsanā-vārttika
Vaṭ. Si	Vaṭeśvara-siddhānta
Vā. Pu	Vāyupurāṇa
VJ	Vedāṅga-jyotiṣa or Jyotiṣa-vedāṅga
Vend	Vendidad
Vet. P	Vetikkampavidhi
Vid	Videvdat
Vi. Pu	Viṣṇudharmottara Purāṇa
VP	Vinayapiṭaka
VP. Culla	——— Cullavagga
Vṛ. Āyur	Vṛkṣāyurveda
VV	Vyomavatī
Yā. Smṛ	Yājñavalkya-smṛti
YV	Yajurveda, Yajurveda Saṃhitā
YVK	——— Kṛṣṇa
Yt. R	Yantrarāja or Yantrarājāgama
YA	Yogārṇava
YR	Yogoratnākara
YSN	Yogosudhānidhi
Y.Sū	Yoga-sūtra
YVa	Yoga Vaśiṣṭha
YY	Yogayātrā

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2 line* 22, read ',' for '.' after 'neolithic'

54 line 30, read 'sizable' for 'sizeable'

126 Footnote, read 'Nadvi' for 'Nadri'

189 line 34, read '*bhāvita*' for '*bhavita*'

204 line 2, read '114' for '58'

231 2nd sub-heading, read '*VĀJĪKARAṆA*' for '*VĀJĪKARAYA*'

249 line 16, read 'tranquillization' for 'tranquilization'

249 line 19, read 'tranquillized' for 'tranquilized'

255 line 19, read '*Aśvaśāstra*' for '*Aśvaśstra*'

268 line 24, read 'pervades' for 'prevades'

274 line 4, read 'Lavoisier' for 'Lavoiser'

275 line 23, read 'Lekhania' for 'Lekhahia'

285 Footnote, line 5, read 'Atranjikhera' for 'Atranjikheda'

287 line 28, read 'Qila' for 'Quila'

289 line 25, read 'Hittites' for 'Hittitics'

292 line 21, read 'lens-like' for 'lense-like'

302 line 26, read 'Waziri' for 'Naziri'

302 Footnote, line 1, read '*Consultations*' for '*Cousultations*'

317 Footnote, line 1, read '*Y.Sū.* 4.1' for '*Y.Sū.* 50'

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321 line 24, read '*kanyā* or *kumārī*' for '*kanyā kumārī*'

327 line 11, read '*lamarckii*' for '*lamarkii*'

327 line 25, read '*kanyā* or *kumārī*' for '*kanyā kumārī*'

338 line 9, read '*Wrightia*' for '*Wrigutia*'

345 line 10, read 'particular' for 'paticular'

348 line 8, read 'constituents' for 'constitutents'

348 line 12, read '*lamarckii*' for '*lamarkii*'

349 line 2, read '*Kanyā* or *kumārī*' for '*Kanyā kumārī*'

356 Footnote, line 2, read 'Strabo' for 'Abo'

359 line 3, read 'inflorescence' for 'infiorescence'

359 line 14, read '*Genandropsis pentaphylla*' for '*Gynandropsis pentaphyta*'

443 read 'Fig. 8.12' for 'Fig. 12'

489 Footnote, read 'p. 5' for 'p. 17'

581 line 23, read 'fistula' for 'fistual'

584 line 2, read 'Artaxerxes' for 'Artaxeses'

587 line 20, read '*Kitāb*' for '*Kital*'

601 line 3, read 'Delisle' for 'Delise'

602 line 12, read 'Rennell' for 'Rennel'

603 line 9, read 'and' for 'adn'

605 line 35, read 'Mookerjee' for 'Mukherji'

653 read 'Nadvi' for 'Navri'

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* Heading and sub-heading not counted.